AD/A-000 436

# A PLAN FOR THE AUTOMATION OF THE DE 1052 CLASS OF NAVAL SURFACE SHIPS

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Purdue University

Prepared for:

Naval Ship Systems Command
Advanced Research Projects Agency

1974

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AD/A-000 436

# A PLAN FOR THE AUTOMATION OF THE DE 1052 CLASS OF NAVAL SURFACE SHIPS

Fourth Quarterly and Final Report
March 1, 1974 - May 15, 1974
Contract No. ~~N00024~~ N00039-73-C-5483
Naval Ship Systems Command

Sponsored by
Advanced Research Projects Agency
ARPA Order No. 2425

REPORT NUMBER 61
Purdue Laboratory for Applied Industrial Control

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ARPA Order Number: 2425

Program Code Number: 3G10

Name of Contractor: Purdue Research Foundation

Effective Date of Contract: 16 May 1973

Contract Expiration Date: 15 May 1974

Amount of Contract: $99,000.00

Contract Number: N00024-73-C-5483

Principal Investigator and Phone Number:
Theodore J. Williams - 317/494-8425

Project Scientist or Engineer and Phone Number:
Theodore J. Williams - 317/494-8425

Short Title of Work: SURFACE SHIP AUTOMATION

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# PREFACE

This report constitutes the Fourth Quarterly and Final Report under Contract N00024-73-C-5483 with the Naval Ship Systems Command, United States Navy, under Advanced Research Projects Agency (ARPA) Order 2425. As such it presents the plan for automation of the Destroyer Escort (DE 1052) Class of Naval surface ships which was the basic objective of this study. The work reported here was carried out by personnel of the Purdue Laboratory for Applied Industrial Control, Schools of Engineering, Purdue University, with the assistance of personnel of Specialized Systems, Incorporated, Mystic, Connecticut. Specialized Systems, Incorporated, served as a subcontractor to Purdue University in pursuing this work.

The Statement of Work of the above contract as modified by subsequent action reads as follows:

> "Conduct a thorough review of the present state-of-the-art, including contacts with personnel and companies actually engaged in building and operating automated surface ships, and Navy personnel at the Naval Ship Research and Development Center
>
> Examine advanced automation technologies that may be applied and evaluate them from the standpoint of the uniqueness of the naval environment.

Make a detailed study of the maximum possible automation of the DE-1052 class warship and develop the associated benefits, personnel savings, and reliability effects.

Develop a specific detailed plan for the actual implementation of the automation proposed for the candidate ship including establishment of a criteria for development contractor selection."

These have been carried out during this study and are reported in our previous Quarterly Reports (11, 13, and 17) or in this present Report. Associated cost and monetary benefit data are being prepared by personnel of the RAND Corporation, Santa Monica, California.

We are indebted to Commander John Dachos of the Naval Ship Research and Development Center (NSRDC), Annapolis, Maryland, for permission to use the Integrated Bridge Concept reported in Chapter VIII of this Report. This design was developed by Human Factors Research, Incorporated, Goleta, California, for NSRDC and is reported herein in lieu of the development of still another design for this function.

The authors acknowledge with gratitude the technical contributions of many organizations and individuals in the development and completion of this work. The following should be especially mentioned: Mr. Morten L. Buckberg, Naval Ship Engineering Center, Mr. Arthur Chaiken, Naval Ship Systems Command, Commander John Dachos, Annapolis Laboratory, Naval

Ship Research and Development Center, Annapolis, Maryland; Human Factors Research, Incorporated, Goleta, California; the Officers and Crew of the USS BARBEY (DE 1088) especially Commander Thomas B. Schmidt, Commanding Officer; the Salen Shipping Companies, Stockholm, Sweden, especially Mr. Nils Friberg, Chief Inspector, and Captain Bengt Svensson and Chief Engineer Evald Sjölund of the T/T SEA SERPENT; Kockums Mekaniska Verkstads AB, Malmo, Sweden, and Mr. Leif Sten, Electrical Engineer of that company; and finally the several American automatic control system suppliers who verified the technical feasibility of the systems presented herein but who do not wish their names presented here because of their proprietary considerations.

This research was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by the Naval Ship Systems Command under Contract N00024-73-C-5483.

Dale A. Halverstadt
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# SUMMARY

This report presents a description of a microcomputer-based, overall, ship operation automation system which can be developed for the DE 1052 Class of U.S. Navy surface ships. All components of this system have already been developed for single function use or are presently in final product test phases for such use. The total system has not yet appeared in its complete form as presented here. Development work needed would thus involve only the engineering, production, installation and test of the overall coordinated system.

Use of such an overall automation system on the DE 1052 should permit a crew reduction of the order of 75-100 men from presently proposed manning schedules while maintaining or even increasing the ship's fighting ability and its capability of responding to any emergency.

Economic factors concerning the proposed control system and the associated manpower reductions are contained in a companion Report being prepared by the RAND Corporation, Santa Monica, California.

Much development work has been carried out in recent years on the computerized automation of the operational functions of various classes of merchant ships and in many cases the resulting systems are now well accepted applications in these vessels. The system developed herein is a consolidation, coordination, and further development of the techniques

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applied here to meet the needs of Naval vessels. In addition, recent developments in the socalled micro computer systems and in serial-highway, data-transmission systems promises to greatly reduce the costs of such installations.

# CONCLUSIONS AND RECOMMENDATIONS

As a result of a one year's study of the requirements of the DE 1052 Class of U.S. Navy escort vessels, of the status of industrial computer control hardware developments, and of the state-of-the-art of commercial ship automation, the present investigators present the following conclusions concerning the automation of the operational (noncombatant) functions of the DE 1052 Class of ships:

1. Recent developments in the large scale integration of electronic circuits has produced microcomputer models with a very high capability and extremely low cost. At the same time communications research has produced very high-speed, serial data systems which are similarly reducing the costs of multi-computer system communications. From these components, extremely reliable multicomputer control systems can be developed to automate all of the optional (non combatant) functions of a warship or of a commercial ship.

2. Every separate function involved in the operational (non combatant) performance of a sea going vessel has been automated by means of a digital computer based system and proven under actual at-sea conditions by at least one organization (domestic or

foreign). Many of these trials involved several different functions. Several of the resulting systems have now been generally accepted for shipboard use (such as satellite navigation systems and anti-collision systems).

3. No ship has yet been built with all the possible automation systems collected together in an overall coordinated digital computer based system. The state-of-the-art is such, however, that it is felt that this can and will be done in the near future.

4. Availability of such an automated system should permit a reduction of the order of 75-100 men (based on the assumptions used) from the current manning table of a DE 1052 Class ship while maintaining or even increasing the ship's fighting ability or its capability of responding to an emergency, through the increased reliability and speed of response of the automated elements compared to human capabilities.

In view of the above, the following Recommendations are offered:

1. The overall digital computer based control system should be developed, installed, and tested on a DE 1052 Class ship.

2. To prove the operability and reliability of the

system described herein, a land based test utilizing the ARPANET Computing Network and existing Naval and Maritime Administration facilities as described in Chapter X of this report should be carried out prior to the sea trials of Item Number 1 above.

3. In order to implement the test of Item Number 2 above a study should be started as soon as possible to define the parameters, timing, and costs, and to detail the arrangements for the tests.

# CHAPTER I

# INTRODUCTION

## OBJECTIVE

The objective of the work reported herein has been to develop a plan of action that would lead to the maximum automation of a U.S. Navy surface warship. Such a project would be designed to demonstrate a significant reduction in the number of surface ship operating personnel while at the same time enhancing the economy of operation and the Navy's traditional requirements for reliability. The ultimate goal of this development would be to achieve a marked reduction in the life cycle operating costs of the ship in question.

This project will take advantage of the latest available industrial developments in small-scale, generalized, remote, direct digital control modules and other applicable recent developments. This will help to assure that the control system which is finally proposed here will incorporate the best possible combination of available control methods and devices and assure the highest possible reliability and performance.

In developing the system to be described herein all existing ship systems must be examined as to their adequacy of response speed and operating characteristics to interface

with the contemplated system. If not, appropriate changes must be made in one or the other systems (existing or proposed) to assure overall system compatibility.

## BACKGROUND

### SOME APPLICATIONS AND BENEFITS OF COMPUTER CONTROL IN THE FIELD OF COMMERCIAL SHIP OPERATION AUTOMATION

The field of shipping encompasses many operations that may and possibly should be automated (3, 4, 10, 11, 12, 13, 14, 15, 21, 22). Although the basic missions of naval and commercial ships differ markedly some functions are equivalent or identical on both. Those functions that are sufficiently similar and for which computer control can provide benefits are briefly covered in the following paragraphs.

### Navigation and Ship Control Systems

A serious problem area facing the operation of commercial surface ships relates to ship size, maneuverability and traffic density. The increasing use of large ships such as supertankers makes the ship control and navigational functions much more critical since these ships are much less maneuverable than the smaller ships in use in the recent past.

It has been shown that a routine stop of a 200,000 ton tanker can take up to five miles and a crash stop up to two miles. The physical dimensions of supertankers and other

large ships can also cause problems during docking and other maneuvering operations. To overcome some of these problems, development efforts are underway to produce reliable ship control and navigation systems to avoid groundings and collisions with other ships or fixed objects. With the increasing traffic density, the anti-collision ship control requirement is almost impossible to solve without some form of rapid and efficient automatic anticollision system. (15).

It has been claimed that analysis of many collisions indicates that the main problem of ship control utilizing radar navigation is the limited capacity of human beings in utilizing the information available on the plan position indicator (PPI) with an adequate speed and accuracy (15). The PPI is a radar-based device that indicates present positions of ships and fixed objects within the range of the radar. The ability of the ship's operating personnel to judge relative speeds and direction of movement of various objects cannot be relied upon to avoid possible collisions. Computer-aided devices can be added to the PPI to indicate the history of movement of all tracked objects as well as its own ship and calculate the closest point of approach (CPA) as well as the optimal maneuvering to be used to avoid collisions based on the history of tracked targets and the capability of its own ship (15).

The costs of operation of new ships used to transport cargo makes routing an ever increasing problem Optimal

routing is of grave concern to the owners and operators of fast vessels such as container ships. In order to accomplish this, better methods of position fixing needed to be developed. In addition, weather routing is becoming more important in the development of a "least time track." This is accomplished using forecasts of weather and sea conditions and a description of the ship's speed as a function of weather and ocean conditions. The results of such weather routing can be reduced sailing time, reduced cargo and hull damage, or increased passenger comfort (15).

Optimal navigation to minimize sailing distance and time can be accomplished using many types of position fixing devices as well as the above mentioned weather routing concept. Computer assistance can be valuable in analyzing position data and history and correcting the navigation track to account for wind and current drift and other factors. This will entail minimizing a performance index consisting of the most critical ship routing variables such as time, and fuel and weather constraints. Extremely accurate position information can be obtained through the use of many devices which are currently available and have been thoroughly demonstrated at sea (15).

There are problems associated with docking and navigation in restricted waters where human judgment cannot be relied upon to provide optimal navigational and maneuvering control due to the many factors involved. Computer assistance can provide safe maneuvering when docking or in restricted waters by

continuously analyzing and monitoring water depth, ship speed, direction of ship movement, and distance to the target destination as well as the dynamic response of the vessel to the maneuvering orders (15, 16, 18).

Propulsion Systems

The automation of the power plant on board ship is probably the most popular application of computer control in ship operations. The requirements for maneuverability and the variable conditions imposed on the power plant make it a prime candidate for automation. The motivation for automation of the propulsion plant is supplied by many factors such as reduced manning requirements, safer and more reliable operation, lower fuel consumption, and less down time and fewer repairs (3, [illegible], 12, 15, 18, 20, 22).

There are four principal functions generally performed by a propulsion control computer. These functions in the order of their implementation have been (15):

1. Data logging and data processing.

2. Operation and alarm system.

3. Automatic time-sequenced start-up and shut-down.

4. Control functions.

They are briefly discussed below.

Data collection, data logging, and data processing tasks are undertaken for many reasons. The course of action taken

prior to collision, grounding, or other situations that are subject to legal investigation can be stored by the computer and produced as evidence. Operating data helps to identify failures leading to system breakdowns and aids in the maintenance and operating functions of the engineering personnel. The operational efficiency of the propulsion system can be deduced and the consumption of fuel and steam can be calculated. Long term operational decisions and maintenance policies can be evaluated in the light of the data collected and future designs or alterations can be justified based on real data (15).

Automatic alarms and safe operation functions remove the task of condition monitoring from the operating personnel. Safety checks and corrective actions as well as diagnostic routines to pinpoint any malfunction can be performed by the computer. Automatic operation allows variable limits for alarm monitoring and does not require continuous training of personnel in the operation of the equipment (14, 15, 18, 20).

Automatic time-sequenced start-up and shut-down of equipment involves many functions previously performed by the engineering personnel on board ship. These functions are: (1) the advancement of a sequence step by step until the desired state of operation is reached, (2) checking before each step to ensure all safety and operating conditions are met, and (3) controlling all transient variables within safe operating limits (14, 15, 18, 20).

The advantages to be gained by using automatic start-up and shut-down procedures are safer, more rapid, and more efficient changes in operating status, savings in personnel and automatic corrective action and prevention of system or component damage in the event of the failure of a component, by the start-up of standby units. This permits considerable savings to the owner of the ship without sacrificing safety or reliability in the operation of the propulsion equipment.

Automatic control of the propulsion equipment is possible with the use of computer-actuated mechanisms and sensing devices. Computer control has some distinct advantages over previous manual systems of control. Some of these advantages are (15):

1. Simplification and resulting economic savings in instrumentation.

2. Flexibility in control parameters.

3. Compensation for non-linear operational effects in and undesired response from instruments and actuators.

4. Control based on values of variables that cannot be measured directly such as shaft horsepower, flow or enthalpy.

5. Wider operating range of plant variables.

6. Automatic compensation of control parameters as the characteristics of the equipment change with time.

7. Quicker and more consistent response of the control system.

8. More precise control.

9. Ability to operate with unattended machinery spaces.

10. The engineering personnel are freed from having to be at the controls at all times.

Ship Communications and Management

The optimization of fleet operations is a difficult problem due to the variety of factors that influence the operation of a large number of vessels. For large fleets, it is desirable to know the location, present status, and predicted future status of each ship in order to schedule future operations of each member of the fleet (15).

A computer system can aid in the operation and management of a large fleet by undertaking many of the routine tasks associated with this supervision and control. The computer system can communicate with the fleet management office, indicating status, predicted future status, position, and much other important information concerning each vessel of the fleet. In addition, the computer can calculate crew wages, overtime, taxes and deductions, and can monitor and control ship's stores and other functions that have to do with the crew's health and condition. The shipping documents and

paperwork can be generated automatically and records can be kept on repair and maintenance (15).

The above discussions have dealt with the general applications and concepts of computer control and its specific uses in the commercial ship operation field. The benefits to be realized by such a system of computer control have been presented in part and briefly discussed in a general context as pertinent background information for this project.

PRESENT PROJECT

On May 16, 1973, the Naval Ship Systems Command issued Contract Number N00024-73-C-5483 for the project entitled, Automation of Naval Surface Ships, to the Purdue Research Foundation of Purdue University. This project had the following objectives and tasks:

OBJECTIVES

1. Develop a plan of action for a project for maximum automation of a U.S. Navy surface warship.

2. Develop a set of potential benefits and related economics versus probably project costs. Predict the resulting reduction in vessel life cycle costs.

3. Determine the effect upon ship operating personnel and identify only appropriate Navy operating procedures and associated regulations which would be

affected by and may limit U.S. Navy surface ship automation.

4. Determine the net effect upon overall ship reliability related to utilization profiles and overhaul and maintenance cycles.

TASKS

1. Conduct a thorough review of the present state-of-the-art, including contacts with personnel and companies actually engaged in building and operating automated surface ships, and Navy personnel at the Naval Ship Research and Development Center.

2. Examine advanced automation technologies that may be applied and evaluate them from the standpoint of the uniqueness of the naval environment.

3. Make a detailed study of the maximum possible automation of the DE 1052 class warship and develop the associated costs, benefits, personnel savings, and reliability effects.

4. Develop a specific detailed plan for the actual implementation of the automation proposed for the candidate ship including establishment of a criteria for development contractor selection.

This work was assigned to the Purdue Laboratory for Applied Industrial Control of the Schools of Engineering of the University. In addition, a subcontract was issued to Specialized Systems, Incorporated, Mystic, Connecticut, to cooperate in the pursuit of the work of this contract.

Subsequently Objective 2 and that part of Task 3 entitled, "-and develop the associated costs, benefits, personnel savings-" has been transferred by the Advanced Research Projects Agency to the RAND Corporation, Santa Monica, California, and is being pursued by them as part of another project.

The Advanced Research Projects Agency has supplied the funding for the present project under their Order No. 2425 to the Naval Ship Systems Command, U.S. Navy. The project has been supervised and monitored by personnel of the Naval Ship Systems Command and the Naval Ship Engineering Center.

Task 1, concerning the review of the state-of-the-art, was carried out during the first and second quarters of this study and was reported in our first two quarterly reports as follows:

1. Kern, D. H., and Williams, T. J., Some Reports on the State-of-the-Art in Automation of Modern Merchant Shipping; Volume I - T/T Sea Serpent, Volume II - Conferences and Visits, Report Number 55, Purdue Laboratory for Applied Industrial Control, Purdue University, West Lafayette, Indiana, August 15, 1973.

2. Halverstadt, D. A., Kern, D. H., and Williams, T. J., _A Bibliography of the Field of Ship Operation Automation_, Report Number 58, Purdue Laboratory for Applied Industrial Control, Purdue University, West Lafayette, Indiana, December 1, 1973.

Objective 3 has been undertaken principally by Specialized Systems, Incorporated, and their study has been reported in the Third Quarterly Report of the project as follows:

Scott, M. T., Kern, D. H., and Williams, T. J., _An Analysis of Personnel Effects and Naval Regulation Considerations in the Automation of Naval Surface Ships_, Report Number 60, Purdue Laboratory for Applied Industrial Control, Purdue University, West Lafayette, Indiana, March 1, 1973.

Because of the very great interest in the DE 1052 Class of U.S. Navy Ships in several on-going ship improvement studies it has been chosen as the basis for this investigation as well. A specific study was therefore undertaken to determine the maximum extent of automation that could reasonably be provided. This would comprise Task 4 and is presented in this Report.

## DETAILS OF THE DE 1052 CLASS DESTROYER ESCORT AND ITS OPERATION

The DE 1052 Class Destroyer Escort is a surface ship

of the United States Navy with the following characteristics (8):

| | | |
|---|---|---|
| Length (overall) | 438' | 0" |
| Length (between perpendiculars) | 415' | 0" |
| Breadth (molded maximum) | 46' | 10" |
| Depth (molded) | 28' | 9" |
| Height of highest projection above design waterline | 120' | 9" |
| Displacement (estimated full load condition) | 4018 | tons |
| Draft - mean (estimated full load condition) | 15' | 0" |

As can be seen from the above dimensions, the DE 1052 class ship is a relatively small surface ship designed to escort other ships in open water and fulfill an antisubmarine warfare mission. For this purpose it is fast and has maneuverability and sea-keeping qualities.

To carry out the wartime mission, the currently authorized full complement consists of approximately 275 men including 19 officers, 17 chief petty officers, and 239 other crew members (17). Their responsibilities include the operation of the ship in any situation from a cold iron watch in port to full battle conditions. The number of equipment functions is quite large and the operation of all equipment on board the ship is a complex task requiring knowledge of the physical plant and its characteristics.

## Machinery

The machinery found on board the DE 1052 class vessel is discussed in this section along with a brief account of a

few of the operations that must be performed in the control and utilization of this equipment.

Propulsion of the DE 1052 is by a steam propulsion plant consisting of two high performance, oil-fired boilers which supply steam to high-pressure and low-pressure (HP-LP) turbines driving a double reduction gear which in turn supplies power to a single shaft and screw propeller. The plant is rated at 35,000 SHP at 240 propeller RPM. For electrical power three turbo-generators are located in the forward auxiliary machinery room and a single diesel drive generator is located in the aft auxiliary machinery room. The usual auxiliary machinery is provided to support the propulsion system and hotel services. A partial list of the main machinery and auxiliaries is exhibited in Table I (8).

The present system on the DE 1052 Class vessel utilizes many independent analog control loops for controlling several functions of the ship and its machinery plant. The major control systems of interest are described briefly in the following paragraphs (8).

The boiler feedwater system consists of a three-element, air operated, feedwater regulator to provide control of the water level in the boiler. The elements of control are steam flow, water flow, and water level.

The water level in the deaerating feed tank is controlled by automatic actuation of makeup feed and excess feed valves. Both of these valves are closed when the normal water level in the deaerating feed tank is reached.

TABLE I

LIST OF PRINCIPAL ITEMS OF MAIN

AND AUXILIARY MACHINERY

Main propulsion unit - HP-LP turbines, double reduction gears driving a single-screw propeller.

Boilers - (two) - Natural circulation with maximum combined output of 217,000 pounds per hour of steam at 940°F and 1050 PSIG.

Main condenser - 6750 $ft^2$ cooling surface capable of handling 217,000 pounds of steam per hour.

Air ejectors - As required to service condensers and other systems or components requiring vacuum.

Main feed pumps - (three) - turbine driven.

Main feed booster pumps - (three) - motor driven.

Main condensate pumps - (two) - motor driven.

Turbo-generator condensate pumps - (three) - motor driven.

Feed water drain tank pumps - (two) - motor driven.

Turbo-generator condensate circulation pumps - (three) - motor driven.

Main circulating pump - motor driven.

Diesel generator seawater circulation pump - motor driven.

Fire pumps - (four) - motor driven.

Main fuel oil service pumps - (two) - motor driven.

Fuel oil service pump - port use - motor driven.

Fuel oil transfer pump - motor driven.

Air compressors - high pressure - (two) - motor driven.

Air compressors - low pressure - (two) - motor driven.

TABLE I (Cont.)

Air compressors - (two) - turbine driven.

Forced draft blowers - (four) - turbine driven.

Lighting off blowers - (two) - motor driven.

Turbo-generators - (three) - turbine driven.

Diesel generator - (one) - powered by tandem drive diesel engines.

Auxiliary condensers, turbogenerator condensate - (three).

Auxiliary gland exhaust condenser.

Air conditioning refrigeration plants - (two) - motor driven.

Refrigeration plant - ship's stores - motor driven.

Distilling plants - (two) - low-pressure flash type - motor driven.

Boiler water feed pumps are automatically controlled to suit the boiler requirements. One or two of the three sets of booster and feed pumps may be lined up for an automatic startup should the pressure in the discharge header from the feedwater run pump fall below a preset minimum level. Those pumps when lined up for standby feed may draw feedwater either from the deaerating feed tank or from the emergency feedwater tank.

The fuel oil supply system is automatically controlled by maintaining a constant pressure in the fuel oil supply header. Bypass and recirculating lines are provided to allow sufficient pump flow volume even at low boiler loads. An emergency fuel oil shut off valve is located upstream of the fuel oil flow control valve and is automatically actuated in the event of emergency or dangerous conditions in the system.

Forced draft blowers are manually controlled using a Woodward speed governor to control the steam turbine driving mechanism. Lighting off blowers are used when steam is not available to run the main forced draft blowers.

Many critical operations in the functional cycle of the machinery are performed by the operating personnel. This includes boiler start-up and shut-down, condition monitoring of all equipment, adjustment of the fuel-to-air ratio in the boiler firing chamber, and other critical tasks. The partial list of main machinery and auxiliaries exhibited in Table I gives an idea of the magnitude of the operational tasks to be performed by the engineering personnel aboard ship.

Current operations require the attention of qualified operators in the engineering spaces at all times to assure the proper operation of the boilers, turbines, and auxiliary machinery in response to ship maneuvering or in-port requirements. This requires a great deal of information concerning the status, the performance, and the demands on the machinery. In addition, much of the time, the engineering personnel are engaged in routine maintenance and general repairs and cleaning. The introduction of computers to perform the control and monitoring tasks and to take corrective action in the event of an emergency condition would allow a much lower manning level (20).

As an example, with the existing manual mode of operation lighting off a boiler involves the following general procedure which must be followed to check for pre-light-off conditions (8):

1. Auxiliary equipment to be checked for operation per manufacturer's instructions as listed below:

   a. Feed pump.
   b. Fuel oil pump.
   c. Fuel oil heater.
   d. Forced draft fan.
   e. Steam gages.
   f. Water gages.

2. Check all boiler operating valves for proper alignment.

3. Close the following:

a. 150 psi protection steam.

b. Superheated and desuperheated stop valves.

c. Blow-off and water wall drain valves.

d. Chemical feed valve.

e. Economizer vents and drains.

f. Water gage drains.

g. Fuel oil and atomizing steam valves.

h. Hydrostatic test vents.

4. Open the following:

a. Steam drum vent.

b. Steam gage lines.

c. Water gages and atomizing header drains.

5. Secure the superheater protection steam to the boiler.

6. Inspect the safety valve lifting gear.

7. Ascertain all safety gages are removed.

8. Drain the superheater.

9. Control superheater and superheater circulating steam.

All of these operations must be performed manually before filling and lighting the boiler. A computer control system could easily perform all of these functions in much less time than the human operator and with a higher degree of reliability and consistency. In addition, the computer would not forget

to complete any one of the assigned tasks in the proper order in the performance of its operations. This is also true for many other operations that are currently performed manually (3, 4, 19).

A complete account of the manning levels on the DE 1052 class vessels and the possible reductions in manning and other benefits that could be realized from the introduction of automation (computer control) can be found in References 17, 20, 22, and 23. Preliminary estimates indicate that the manning of a DE 1052 class vessel could be reduced in the order of 75-100 men with the potential of enhancing reliability, availability, and efficiency. It is probable also that the operational economies of the ship would be improved by the introduction of computer control (18). Supporting rationale for these estimates of reduced manning is discussed in Reference 23 and will be reported on in detail, including an economic analysis, in Reference 22.

## Navigation and Ship Control

At the present time the DE 1052 Class ships take no advantage of the automation available for the navigation, ship control, and collision avoidance functions from commercial ship sources. Dead reckoning navigation, plotting of LORAN, RDF and OMEGA position lines, and the reduction of celestial sightings are all done by hand. No automatic course control is available, therefore a helmsman is required at the wheel at

all times. In addition, determination of collision possibilities from radar sightings are carried out by hand plotting methods on the radar scope. All of these functions can be completely automated and have been demonstrated at sea in many commercial ships.

LOGISTICS

In contrast to the commercial ship which is generally a specialized cargo carrier of one type or another and thus amenable to the automation of the loading and unloading function for that type of cargo, the naval combat ship such as the DE 1052 loads relatively small amounts of highly varied stores into cramped and scattered locations aboard. In addition, the large numbers of crewmen available, even after the reductions contemplated here, normally take part in such operations. No specific attention has been paid to the stores handling function in this study, however, it is understood that the navy has in progress study and development efforts to improve, both from the standpoint of speed and numbers of men required, shipboard ammunition handling functions.

SHIP COMMUNICATIONS AND MANAGEMENT

This area can be divided into two major classes, first, internal ship communications and, second, external communications and fleet management. The latter area is very highly involved in combat operations and as such is not part of this

study which is confined to the non-combat functions of the ship. The first is one major reason for the large number of personnel on board a naval ship such as the DE 1052 since messengers and phone talkers are used in large numbers to man the redundant communication channels and to relay messages vocally to the Captain and to the other officers. Proposals are made here that should make it possible to eliminate much of this type of manpower, even though a majority of commanding officers today are more comfortable with phone talkers.

# CHAPTER II

# THE PROPOSED OVERALL CONTROL SYSTEM

## BASIC COMPUTER SYSTEM DESIGN FOR AUTOMATION OF A DE 1052 CLASS SHIP

Automation of a DE 1052 Class ship involves a complex system for the automatic monitoring and actuation of many standard marine-type units. These units are distributed through all parts of the ship, but their activities can be divided into functional areas of responsibility as has been shown in similar studies and applications in the commercial shipping industry. This means that failure of any part of the computer system will affect the operation of only a small portion of the overall ship system (18).

Using the above concept, it is possible to define the basic system architecture to be used in developing the automation system studied here. Having developed areas of functional responsibility, yet maintaining flexibility and a high degree of integration, a system of distributed processors has been proposed to effect automation in this environment. Such an architecture provides for an integrated system that may be easily adapted to many systems with a minimum of effort and which dispenses with the existing independent analog control loops.

Applying these ideas to the DE 1052 Class of ships, the

following areas of the ship have been designated as candidates for automation:

1. Navigation and ship control.

2. The propulsion system.

3. The electrical power and other auxiliary machinery.

4. Damage and casualty control.

The basic system architecture for the four areas of functional responsibility utilizes a distributed processor system and provides for the complete interconnection of all separate control units. A sketch of the basic system is shown in Figure 1. Such a system has many benefits that are of great value when installing, operating, or altering the system. Some of these benefits are:

1. Flexible system configuration - distributed subsystems may be modified, replaced, or deleted without upsetting the rest of the system.

2. Graceful degradation - failure in one or more components or subsystems does not cause the entire system to fail.

3. High systems reliability -

   a. Easy to add parallel redundant units and

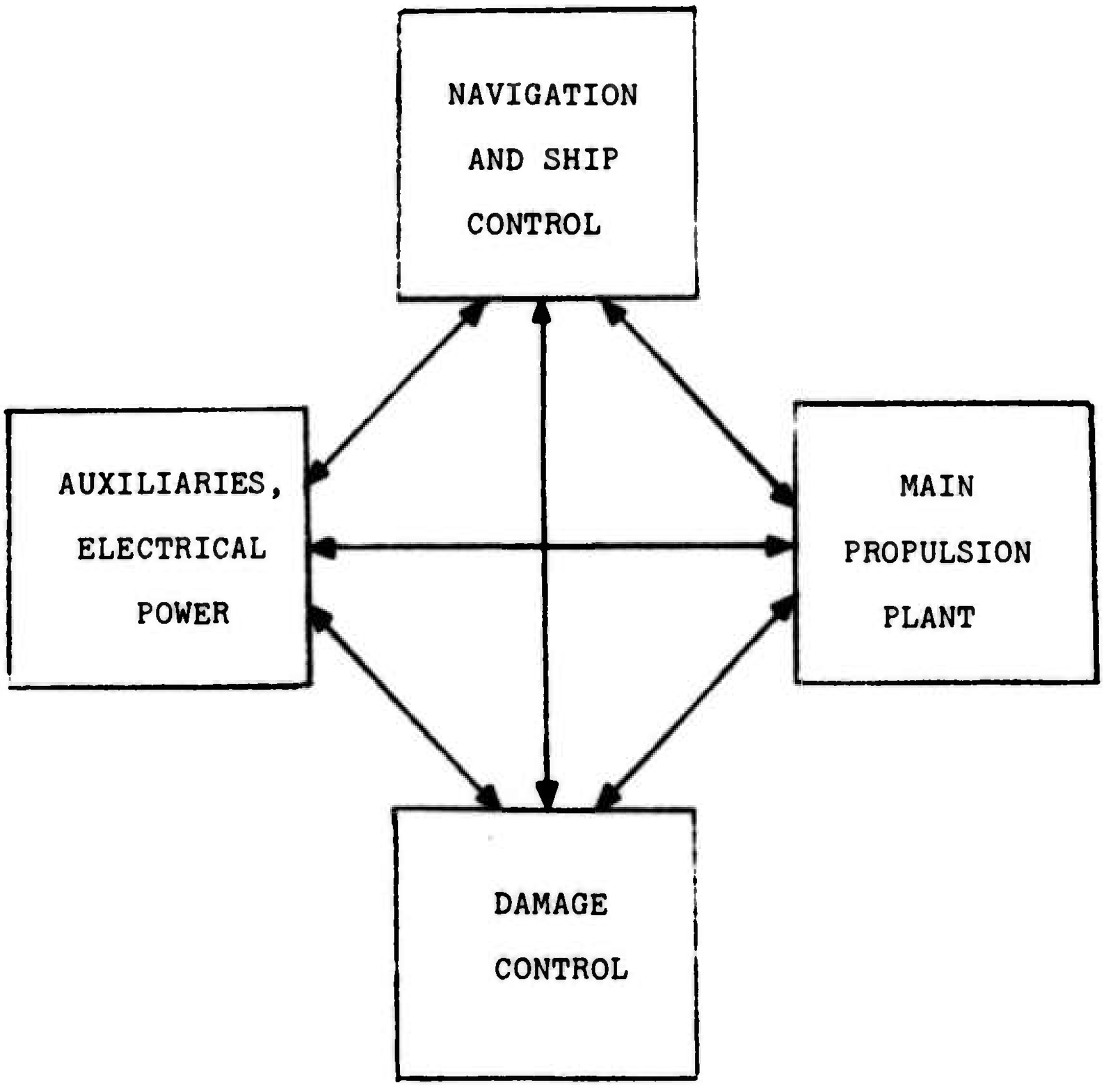



FIGURE 1

SIMPLIFIED SKETCH OF THE DISTRIBUTED PROCESSOR SYSTEM FOR SHIP CONTROL AND AUTOMATION

subsystems can be incorporated to back up and duplicate the function of the main components and subsystems.

b. Transmission of processed information allowing;

(1) Decreased data rates since processors are distributed to functional areas and only processed information need be sent between any two subsystems.

(2) Use of error detection codes allows any fault or casualty condition in the system to be detected and identified by the processor in its area of responsibility.

4. Lower cost due to:

a. Simplified hardware configuration packaging since processors need not be large due to the reduced processing requirements of each processor.

b. Simplified software because functions are carried out by several small, locally responsible processors, not by a large machine that must perform all of the control functions and calculations within the entire control system.

c. Large scale integration technology.

d. Multiple use of standard components. Many different subsystems can use identical hardware to perform varied functions.

e. Ease of incrementally increasing capability since units may be added to the system without drastically interfering with the functions of the rest of the system.

f. Simplified installation since common data channels can be used for processor-to-processor communication. This eliminates the need for individual multiple-wire cables between any two units.

The application of the above principles to the specific requirements for automation of a DE 1052 Class ship results in a system architecutre that incorporates several micro-computers to perform control and monitoring functions within each functional area and a set of supervisory minicomputers controlling the overall system and performing necessary calculations and interrogation functions to support and maintain optimal control performance.

A general sketch of the computer control centers and the data highway common communications channels is shown in Figure 2. Note that all subsystems have access to four separate communications channels since information can be passed in either of two directions through either of the two cable loops comprising the communications channels.

## AN OUTLINE OF THE SYSTEM

An outline of the functions to be included within each of the areas discussed above is presented below:

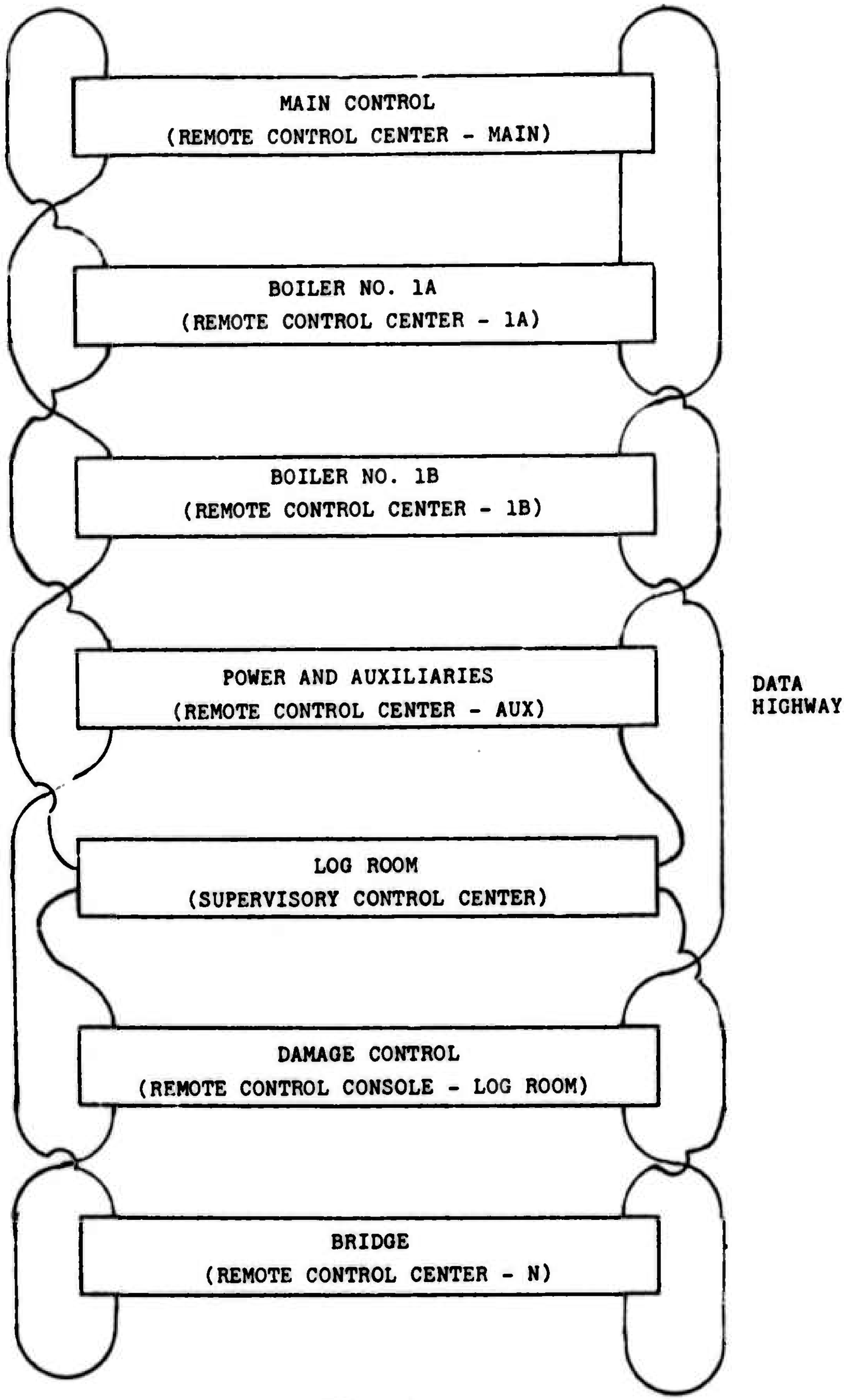



FIGURE 2

GENERAL SKETCH OF THE COMPUTER CONTROL CENTERS AND DATA HIGHWAY COMMUNICATIONS CHANNELS

THE BRIDGE

The automated bridge should include the following functions:

1. A two or three man console type bridge operating station equipped with the following:

    a. Auto pilot.

    b. Remote control of engines.

    c. Anticollision system.

    d. Readout for

        (1) Position in latitude and longitude.

        (2) Course and distance to go.

        (3) Bearing and distance of designated points.

        (4) Station keeping position, etc.

2. Position determination by satellite.

3. Position determination by hyperbolic system.

4. Dead reckoning by electromagnetic log and/or doppler sonar.

The following equipment should be incorporated in the bridge facility.

1. Twin mini-computer system (duplicate) for navigation, ship control and anticollision functions.

2. TRANSIT receiver.

3. OMEGA receiver.

4. PPI presentation device for the anticollision system.

5. Steering station including gyro based autopilot.

6. Dual digital readout units for ship functions, navigation position, etc.

7. Bridge wing control stations.

## THE PROPULSION SYSTEM

The automated propulsion system should include the following functions:

1. Direct control of main engine from the bridge or from the engine room control center.

2. Time based control of engine speed and direction changes with condition adaptation of time base.

3. Monitoring of boiler and turbine and related functions and casualty response on detection of systems danger conditions.

4. Indication of all desired power system variables. Printing of critical variables on demand and at preselected intervals.

5. Automatic light-off of boilers and start-up of steam production.

6. Automated shut down of boiler systems.

7. Simulation capability for system tests.

The following equipment should be incorporated in the engine room computer system:

1. Twin mini-computer supervisory control of the total power train system (situated in Log Room).

2. Redundant micro-computer direct control of each major unit of the system.

3. "Data Highway" communications channels to connect all micro-computers with the supervisory control computer system and the bridge system.

Additional equipment such as controllers, actuators, etc., necessary to complete the engine room automation are described in Chapters III and IV.

THE ELECTRICAL POWER SYSTEM AND OTHER AUXILIARY MACHINERY

The following functions should be provided:

1. Automated start up of both steam and diesel powered electrical generating units.

2. Automatic alignment and synchronization of all electrical generating units.

3. Monitoring of all major electrical trunks and disconnection of any showing faults.

4. Read out of selected system variables at fixed intervals of time or on command.

The following computer equipment should be incorporated:

1. Redundant microcomputer direct control of generation units and of automated switching panels.

2. Connection to "data highway" communications channel for contact with supervisory control system.

Additional equipment such as controllers, disconnects, etc., necessary to complete the automation of the Electrical Power System and other auxiliary machinery is described in Chapter V.

DAMAGE AND CASUALTY CONTROL

The following are needed as part of the Damage and Casualty Control System:

1. Inert Gas system for engine room and boiler spaces.

2. Fire Main isolation loops.

3. Some method of indicating status of water tight compartments including remote closing doors and sea water isolation.

4. Fire Warning system.

5. Wireless communication system.

## COMPUTER EQUIPMENT REQUIREMENTS

Using the microcomputer based controllers described later in this Chapter, Table II presents the total number of these systems and of regular sized minicomputers necessary to carry out the functions listed just above. Table III lists the equipment required to present the data thus developed by the monitoring and control systems to the propulsion system attendants and bridge personnel to help them to properly carry out their functions. Table IV presents the systems capabilities which must be incorporated into the computer systems and their associated programs to achieve the capabilities necessary to match the needs presented.

Figure 2 is a block diagram of the overall control system proposed showing that there are complete remote systems at each of the main locations of the present ship control functions: Main Control, Boilers (separate), Electrical Power, Log Room, and Bridge. A sketch of the type of equipment contemplated at each of the below decks areas, except the Log Room, is shown in Figure 3. As can be seen this is a completely redundant system in terms of sensors, multiplexers, controllers, and operator's displays to assure the maximum possible reliability. This redundancy combined with the additional fail-soft*

* Sufficient separation and redundancy to prevent any instantaneous total failure of the computer system.

TABLE II

PRESENTLY ENVISIONED COMPUTATIONAL HARDWARE
REQUIREMENTS BY CONTROL CENTER LOCATION

| | |
|---|---|
| Main Engine | |
| Dual Micro Computers | 2M * |
| Boilers | |
| Dual Micro Computers each | 4M |
| Electrical Power System | |
| SSTG System - Dual Micro-Computers | 2M |
| Diesel System - One Micro-Computer system | 1M |
| Bridge System | |
| TRANSIT Satellite | 1M |
| Dead Reckoning and Auto Pilot | 2M |
| Anti-Collision | 2Reg ** |
| OMEGA, LORAN, etc. | 1M |
| Log Room | |
| Supervisory and Coordination System plus Damage and Casualty Control | 2Reg |
| Total | 13 Micro<br>4 Reg |

*M - Micro-computer controllers now under development

**Reg - Presently available Mini-computers

TABLE III

PRESENTLY ENVISIONED INDICATOR
REQUIREMENTS VERSUS SHIP LOCATION

| | CRTS |
|---|---|
| Main Engine Control Station | |
| Dual CRTS (AN + V) | 2 |
| Boiler Control Station (Two Stations) | |
| Dual CRTS (AN + V) | 4 |
| Electrical Central | |
| Dual CRTS (AN + V) | 2 |
| Log Room | |
| Dual CRTS (AN + V) | 2 |
| Logger | (1) |
| Bridge | |
| Dual Anti-Collision (PPI) | 2 |
| Dual CRTS (AN) | 2 |
| Logger | (1) |

AN - Alphanumeric Cathode Ray Tube (CRT) presentation

V - Vector Cathode Ray Tube Presentation (i.e., Graphics, etc.)

PPI - Plan Position Indicator (Radar and Anti-Collision)

## TABLE IV

## SOME CAPABILITIES REQUIRED OF THE MICRO-COMPUTER AND MINI-COMPUTER CONTROL SYSTEMS

1. Either of the two redundant micro-computers in each area will be capable of operating from any one of the four data cables of the communications channel of Figure 2.

2. Either of the two redundant micro-computers in each area will be capable of carrying out all control functions of its area of responsibility.

3. Either of the two redundant micro-computers in each area will be capable of driving either one of the two available CRT systems. (see Figure 3)

4. Either of the two local micro-computers in each area will be capable of being addressed by a portable interrogation device for operability testing, readout of constants of system, circuit checks, etc.

5. In common with the central (i.e., supervisory) computer system any functions of the computer systems should be checkable from the external portable interrogator. It should be possible to adjust any systems constant by this method.

TABLE IV (Cont.)

6. Diagnostic programs selected by the main (i.e., supervisory) computer must be able to be run on any of the subordinate micro- computers as an operational check.

7. Main (i.e., supervisory) computer system functions:

   a. Logging of preselected important data.
   b. Logging of new actions during the operation of the plant.
   c. Selection of optimum strategies of operation.
   d. Diagnostics and control of maintenance tests and corrective measures.
   e. Presentation and output of normal operational data as required by regulations.

8. On-line diagnostics of self and of related systems.

9. All systems will operate on a large unit replacement maintenance system basis rather than through actual electronic repair of components and cards. (It should be noted that micro-computer technology will permit such a replacement type maintenance policy at less cost than current practice.)

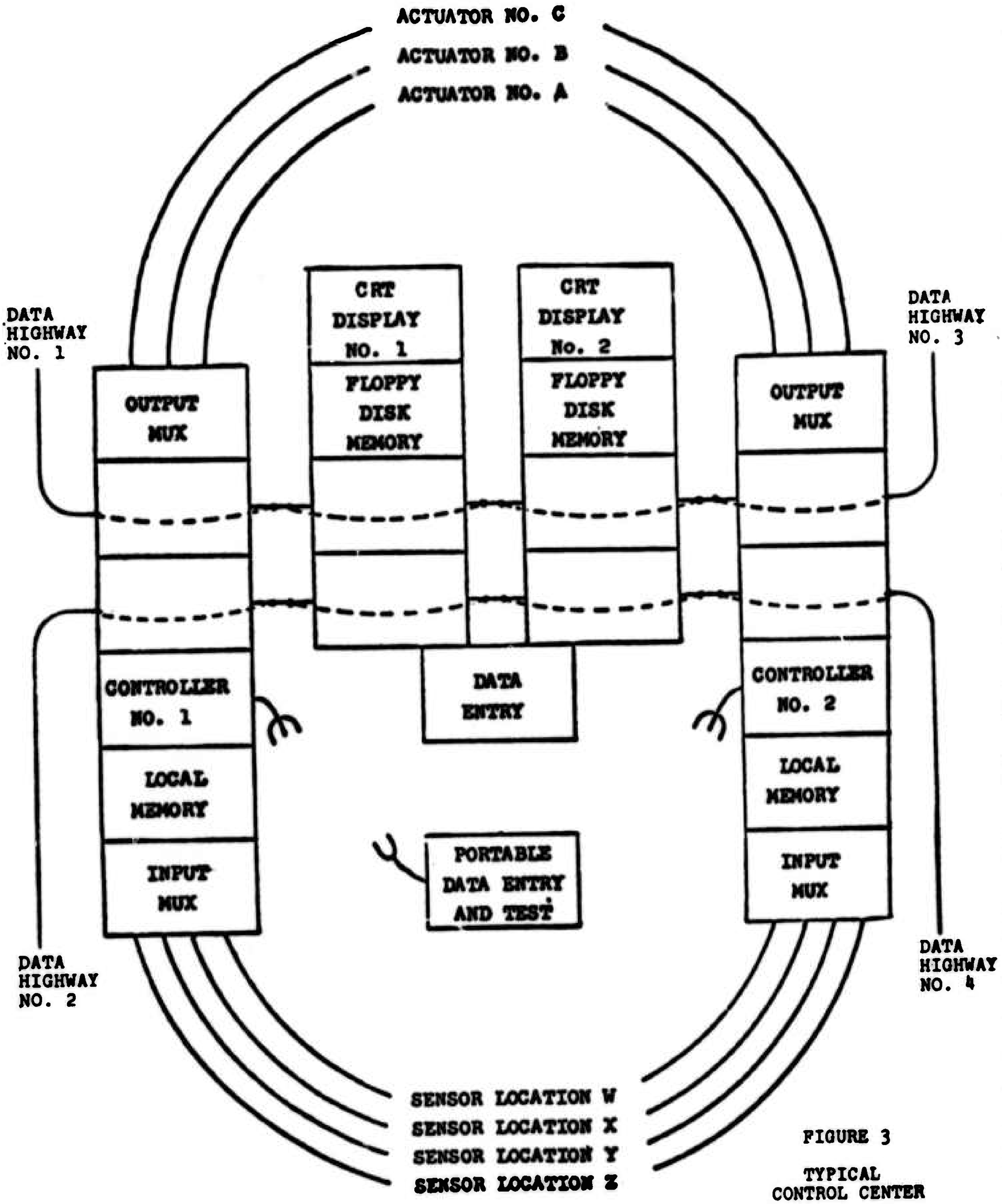



FIGURE 3

TYPICAL CONTROL CENTER

(Is representative of all blocks in Figure 2 except the Log Room and Bridge)

capabilities listed in Table IV should adequately assure this necessary capability.

System and component test and adjustment capability is provided by two different sources. First, a portable interrogation device is supplied to test the operability of the components and their circuits and to test the constants of the system. Any system constant should be capable of being adjusted using this device. Secondly, the main computer maintains a file of simulation and diagnostic programs that can test the operability of any component of the system and check the result of any normal operating routine.

The main computer system must be capable of logging preselected important data and new actions during the operation of the propulsion plant. It also selects optimum strategies of operation and controls diagnostics and maintenance on all parts of the system. Output of normal operational data as required by regulations is controlled by the main computer system.

All systems should be maintained on a replacement maintenance system rather than through the repair of components and cards.

Consistent with the above requirements for the control system components, Figure 3 presents a basic controller configuration that will satisfy the needs of the system. It contains all operating systems, calculation procedures and program logic, and communication interfaces. Inputs to this controller system are provided by sensors and an operator interface as well as

the data highway system. Outputs are directed to actuators, the operator interface, and the data highways. The data highway channels are redundant at each controller site and have the capability to bypass the controller so that a failure in any one controller does not cause the failure of the entire communication system. Figure 4 is a redrawing of Figure 3 to show the actual hardware connections involved rather than the functional blocks previously used to indicate redundancy capabilities.

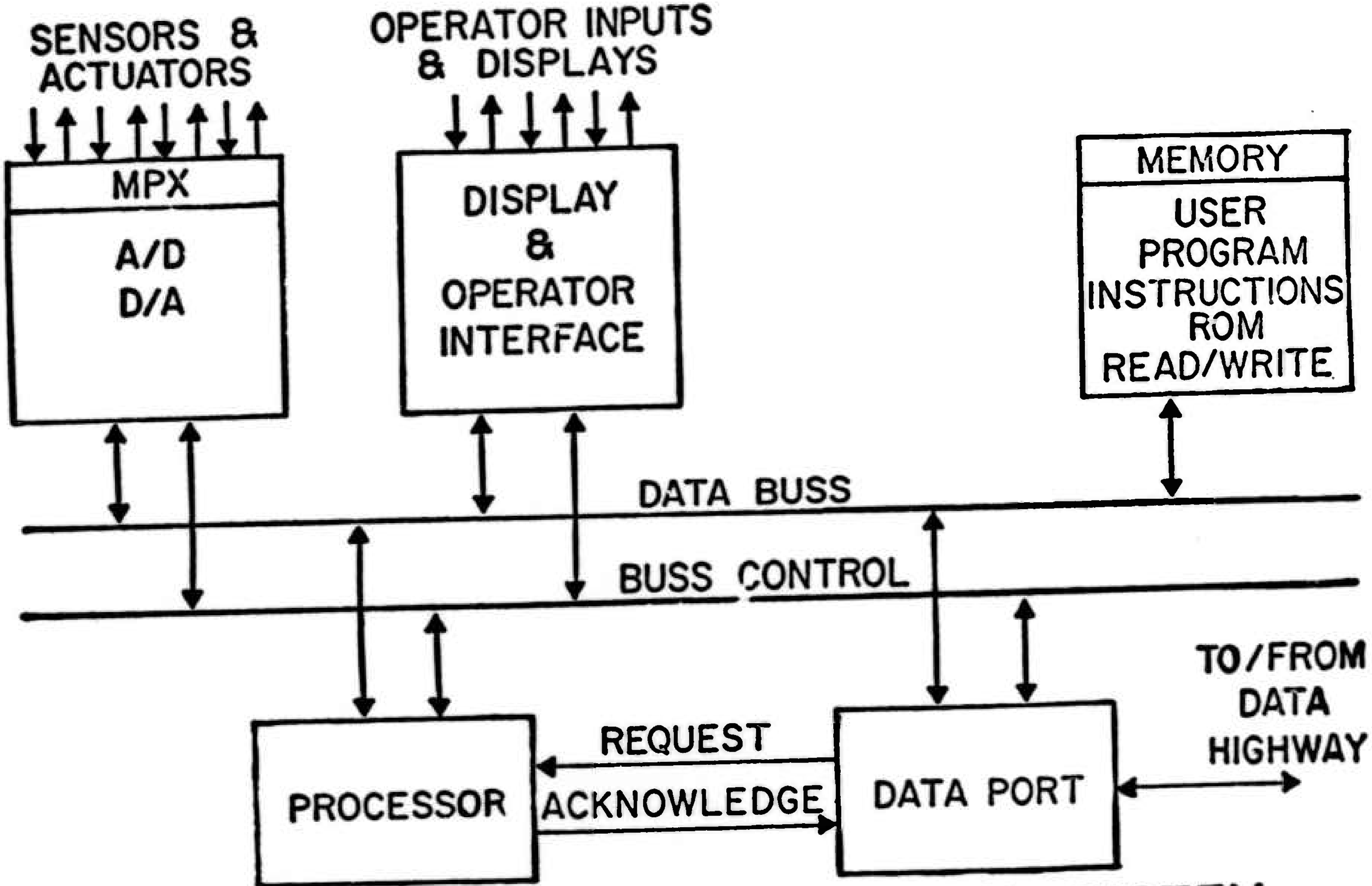
The controllers have a parallel processing capability to enhance the reliability of the system. Each controller has a memory storage capacity of up to 16,000 words at 16 bits per word. The latest electronic technology has been assumed. Each controller can stand alone or serve as part of the data highway integrated computing and control system.

## MAN-MACHINE INTERFACE

The justification for the above type of control presentation centers has been based on the economic benefits to be realized by reduced manning, improved efficiency, and higher reliability as well as other factors. However, up to now, little has been said about the operator's role in the operation of the control system itself and the human engineering problems encountered in the implementation of such a system.

Without the introduction of computer control, the operator has displayed before him almost all the data available on

FIGURE 4




PROPOSED PROCESS CONTROL SYSTEM
BASIC CONTROLLER CONFIGURATION

the operation of the equipment. The vast quantity of this information makes it extremely difficult for the operator to absorb all pertinent data and make reliable and rapid decisions concerning the plant's operation and any necessary actions he should take. The use of the computer in controlling the system takes much of the load off of the operator and delegates to him the role of a systems monitor and repair man. By being provided with the capability of automatic monitoring of process parameters and automatic alarms in the event of failure, the operator is freed to make operating decisions and repairs needed in the day-to-day operation of the physical plant (14).

In order to introduce the operator into the operation of the control system, it is necessary to design an interface between the man and the machine [computer]. The flexibility and adaptability of the digital computers proposed for the implementation of this control system makes them well suited to the inclusion of the human operator as a supervisor, monitor, and decision-maker (21).

There is a set of requirements and concepts for man-machine interfaces that have been well established and documented as being applicable to process control computer systems (21). These requirements can be met easily in the design of the computer system and control centers without eliminating any of the previously discussed equipment or operations. These requirements and concepts for the man-machine interface are (21):

1. Avoid parallel displays mounted on extended panels since they contain more information than the human operator can absorb simultaneously.

2. Process operation information should be displayed on an exception basis.

3. Compact indication of process performance or status should take advantage of pattern recognition display techniques.

4. Data should be grouped to convey knowledge of the operations of natural subsystems.

5. Alarms should be hierarchial, being selectively suppressed as a function of operating state.

6. Manual operation of most control valves should be possible as a redundant feature.

7. History of and trends in past data should be available for operator guidance but hard copy is not essential for this information.

8. Analog displays should be used for qualitative information, digital displays for quantitative information. These two forms can be mixed as required.

9. Available derived variables such as efficiency, quality, etc. should be used as performance indicators rather than simple variables such as temperature, viscosity, etc.

10. A single interface should be provided with all of the functions and information available at any one location.

11. Interfaces should not be compromised to support other functions such as maintenance and management.

## AVAILABILITY

Components such as described in this Chapter are now being developed by all of the major automatic control systems suppliers. Normal product development rates will have such devices available for public announcement by the Fall of 1974 and available for purchase for complete systems installations, such as is contemplated here, by the Spring of 1975. Considering the recommendations to be made as part of this project the above availability will be sufficient for their uses in any contemplated tests of the system described herein.

# CHAPTER III

# MAIN ENGINE CONTROL SYSTEM

## INTRODUCTION

This Chapter begins a detailed discussion of the automatic control functions to be carried out by the computer based control system proposed herein. Most important in terms of possible manpower reductions is the automation of the propulsion plant to achieve an unattended operations status such as is now commonly used with the steam plants of many commercial ships. The control of the engine room and its related equipment is discussed first in this Chapter.

## ENGINE CONTROL SYSTEM

Direct control of the main engine shaft speed and of its direction of rotation from the bridge or from the engine room control center requires the automatic control of the boilers, of steam flow to the main engine, and of supporting auxiliary machinery and systems. The control of the boilers and their auxiliary equipment is performed by separate computer systems designed and installed specifically for this purpose. The boiler control system is discussed in Chapter IV. Some auxiliary systems are controlled by the Boiler Computer Control System. These systems are:

1. Fuel oil.
2. Lube oil.
3. Feedwater/condensate.
4. Combustion air.
5. Main circulating water.
6. Steam dump/steam relief/burner sequencing.
7. Auxiliary steam.

Other auxiliary systems are under the control of the computer systems installed for the supervision of the electric power and auxiliary systems. This computer system is discussed in Chapter V.

The control system proposed for the direct control of the main engine is shown schematically in Figure 5. Control can be effected either from the bridge or from the engine room control center. A minimum of main computer inputs and outputs have been used to reduce system complexity and enhance the system's reliability.

The development of the computer model used by the computer to control the main engine must consider the process dynamics and interactions of the system. The capabilities and performance characteristics of the engines are affected by the characteristics of the boilers and other auxiliary

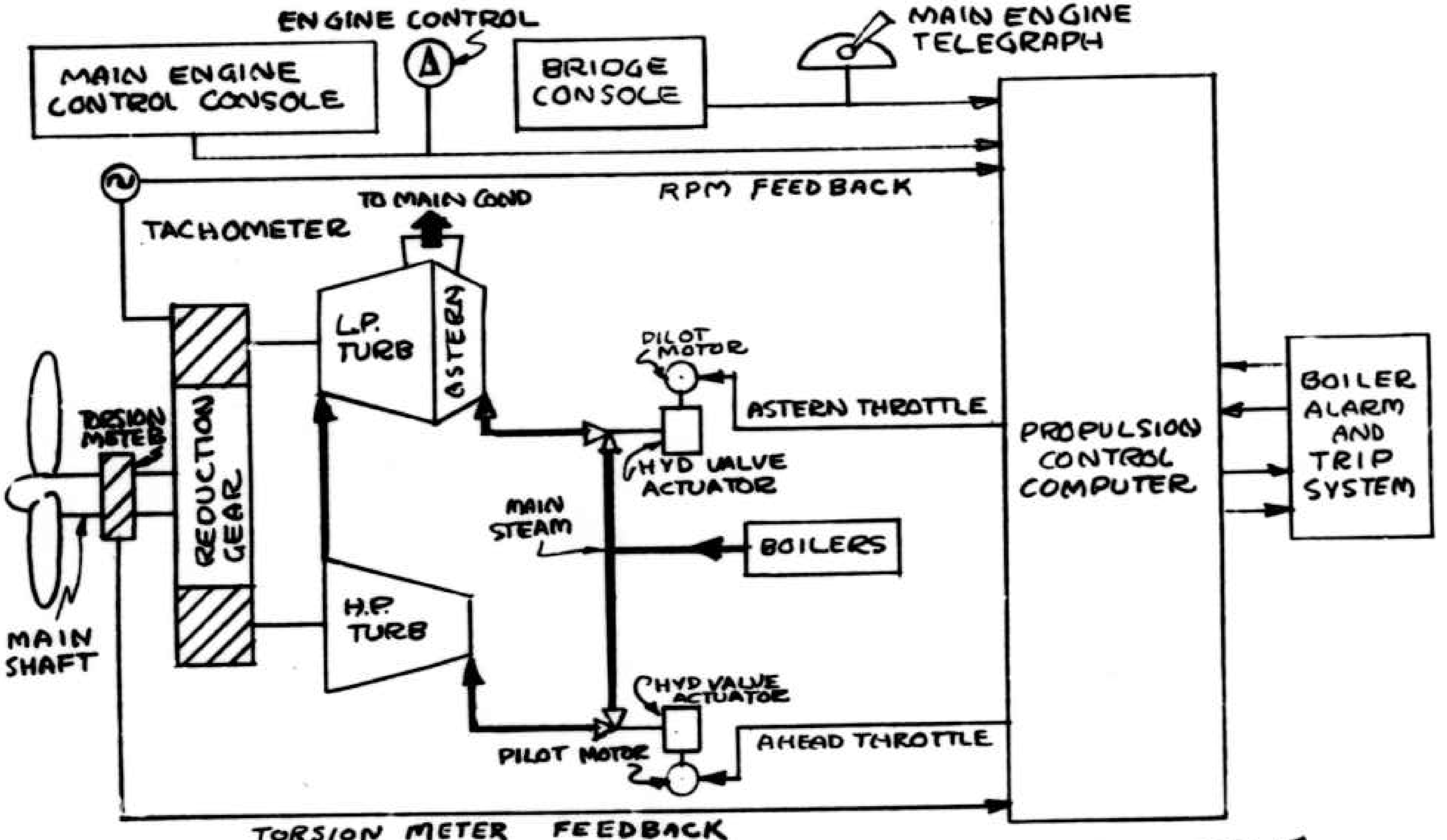



FIGURE 5
MAIN ENGINE
AUTOMATIC CONTROL
SCHEMATIC

equipment necessary to power and service the main engine. The engines also affect the operation of those boilers and auxiliary systems, creating an interactive system. The dynamics of these interactions and the resultant system parameters must be thoroughly investigated before any model can be used for control purposes. In addition, those parameters which relate to the responsiveness of the ship in answering helm orders and throttle commands must be determined. The maneuvering response of the ship is dictated by the particular hull, rudder, and propeller designs and the characteristics of the power train driving them (24).

The desired automation of the propulsion system should include several principal functions and features, most of which have already been successfully applied in the commercial shipping industry. These features are considered essential to the safe and economic operation of an automated ship and are presented as a set of functional requirements for the automatic control of the propulsion equipment and are listed below:

1. Direct control of the main shaft speed and direction of rotation must be possible from the bridge or from the engine room control center with the engine room, the fire room, and the auxiliary spaces unmanned.

2. Computer monitoring of the main engine and boiler functions must occur with provision for an automatic casualty response and/or the automatic blocking

of propulsion plant functions whenever out-of-limit or casualty conditions are detected.

3. Automatic light-off and shut-down of boilers and automatic start-up of steam production must be possible through the computer control system above.

4. Indication using cathode ray tube (CRT) presentation of all desired power system variables with the capability to record or print critical variables at preselected time intervals or on command from ship's personnel must be possible.

5. A simulation capability to run operational checks on any part of the computer control system must be available.

Provision of these five basic features of the automated propulsion control system should be accomplished through the incorporation of the systems concepts and features that are discussed in the following section of this chapter describing the individual control systems and components necessary.

THROTTLE CONTROL SYSTEM

The controls located in the engine room control station and on the bridge should include the following principal features and functions:

1. Direct control of the main shaft speed and direction of rotation using a standard engine order telegraph unit linked to the computer control system.

2. There will be no limitation placed on the rate of actuating movement or on the direction of movement of the telegraph unit. All limitations of engine response will be under control of the computer system.

3. The engine order telegraph will provide the capability to order shaft rotation in the following modes:

   a. Main shaft direction of rotation - "ahead" or "astern."

   b. Main shaft speed in RPM in either the ahead or astern direction.

   c. Ship's speed ahead in knots based on a predetermined ship speed/RPM relation or an EM log input.

   d. Standard engine order telegraph orders such as "full ahead,""standard," "half ahead," etc.

   e. The engine room control center will be able to override the bridge's selection.

A detailed design of the bridge system used in the control of the main engines and other bridge functions has been performed by the Naval Ship Research and Development Center. This design has been included in the discussion of the Bridge System given in Chapter VIII of this Report.

The throttle control system transmits signals from the bridge or the engine room control center to the computer and from the computer to the main engine throttles. A block diagram of this system is presented in Figure 6.

The mechanical system for the automatic control of the main engine is diagrammed in Figure 7. Ordered shaft speed and direction of rotation are transmitted to pilot motors (Item 1 in Figure 7 for ahead operation, Item 2 for astern operation) which drive hydraulic valve actuators (Items 3) opening or closing the throttles as required. Pressure transmitters (Items 7 and 8) indicate steam pressure at the ahead and astern turbines and send this information to the computer. Feedback as to the actual shaft speed is provided by a tachometer-generator set (Item 9). A torsion meter (Item 10) mounted on the main shaft provides information concerning the shaft torque being delivered to the propulsion equipment. All of these Items are shown on Figure 7.

Figure 8 presents a typical times cycle used in carrying out any engine orders selected by the bridge or the engine room control center. These timed cycles are predetermined by system dynamic analyses so that all engine orders will be carried out in a manner compatible with the propulsion plant's characteristics and capabilities. The actual scales of these figures would be determined from actual tests of these characteristics or from manufacturer's specifications.

Monitoring and alarming should be included in the control

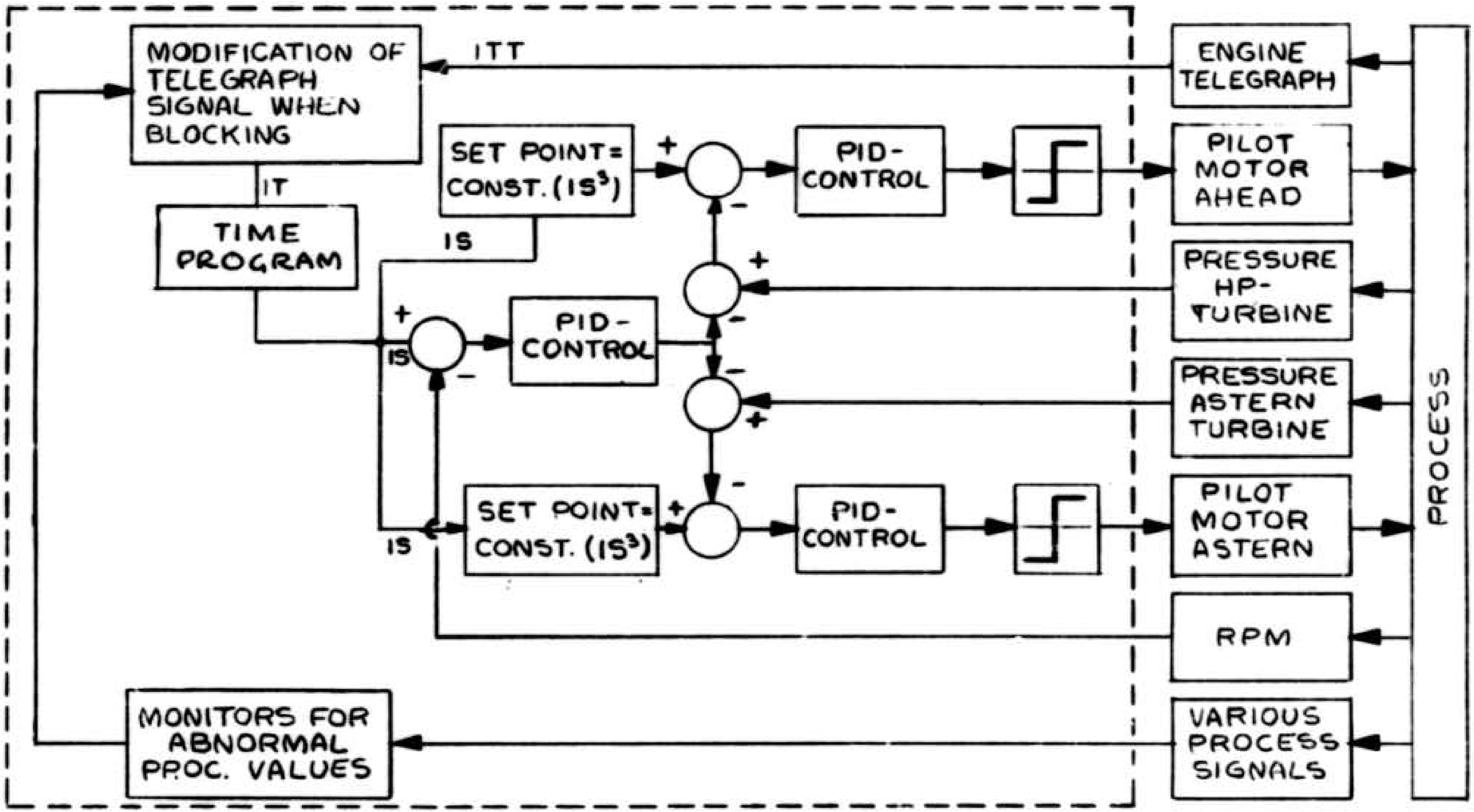



FIGURE 6
BLOCK DIAGRAM-
BRIDGE CONTROL
OF MAIN ENGINE

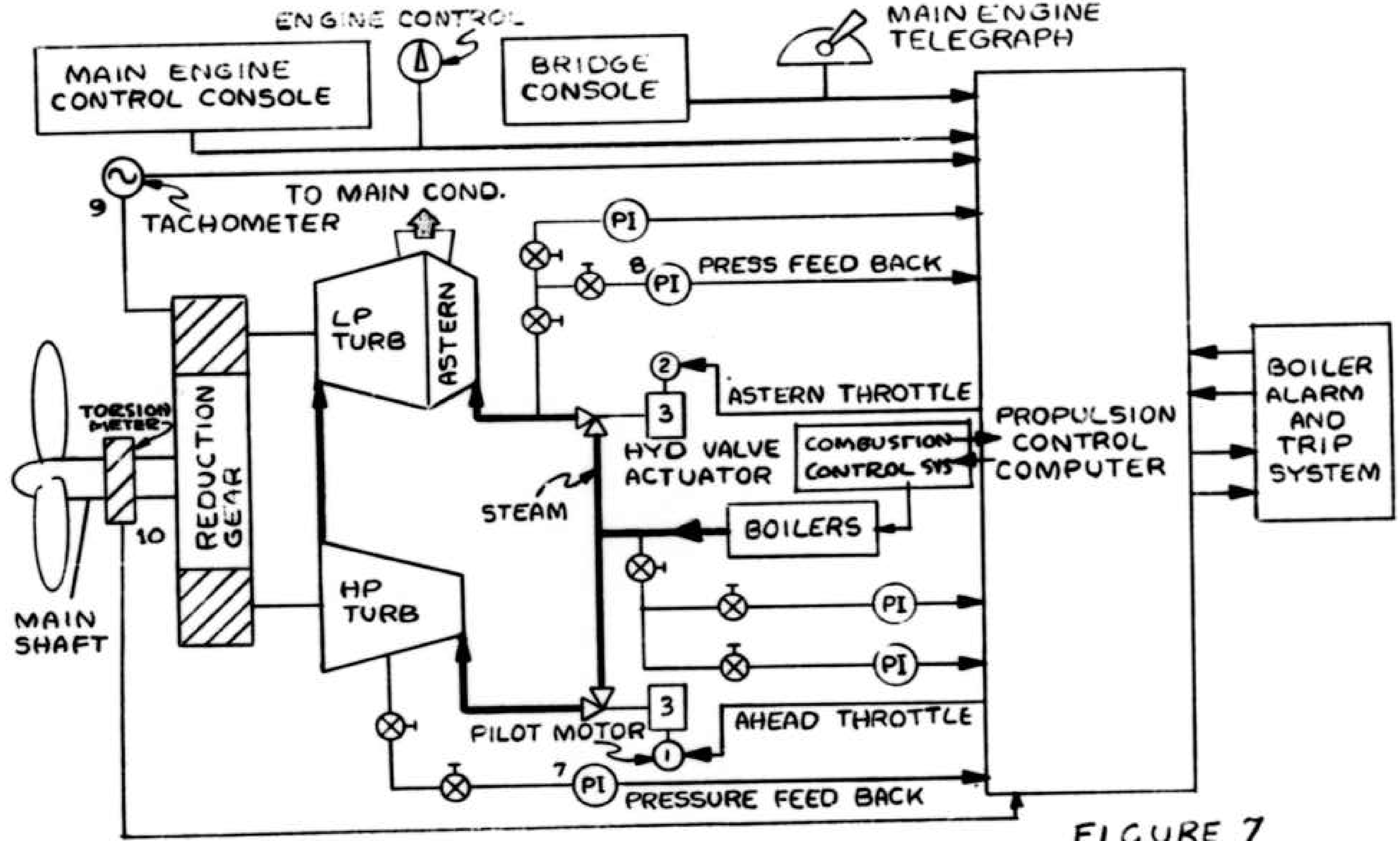
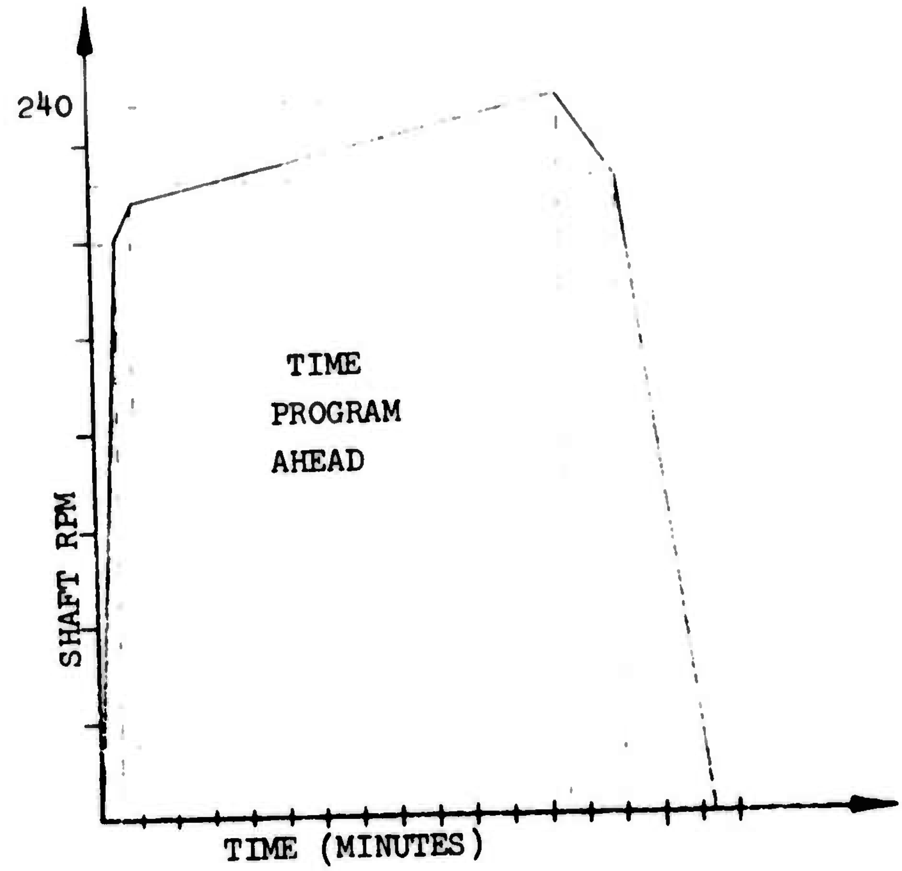



FIGURE 7
MAIN ENGINE
AUTOMATIC CONTROL
SYSTEM DIAGRAM



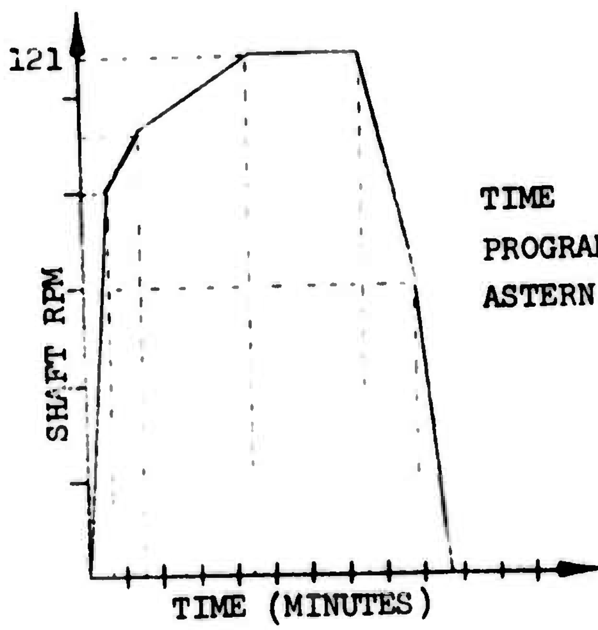




FIGURE 8

TYPICAL ENGINE ORDER TIME CYCLE
AS GENERATED BY THE COMPUTER SYSTEM

system for the main engine to indicate any failure or out-of-limit conditions in any critical component of the engine system. These alarms, categorized in order of importance to the operation of the propulsion system as discussed under Alarms General Requirements in Chapter VII are:

<u>Group A - Main Engine to be Stopped by Computer</u>

1. Main shaft axial displacement beyond limits.
2. HP turbine overspeed/LP turbine overspeed.
3. HP/LP turbine rotor axial displacement beyond limits.
4. Main lube oil-low pressure.
5. Astern turbine exhaust steam - high temperature.
6. HP turbine - excessive vibration.
7. LP turbine - excessive vibration.
8. Turning gear engaged.
9. Manual trip of the engine.
10. Idling cycle failure.
11. Main engine emergency stop from bridge or engine room control center.

<u>Group B - Reduced Main Engine Shaft Speed Ordered by Computer</u>

1. Lube oil to main engine - low pressure*.

2. Lube oil to main engine - high temperature.

3. Astern turbine exhaust - high temperature*.

4. Bearings - main reduction gears and turbines - high temperature.

Group D - Main Auxiliaries Failure

1. Bridge throttle control system failures.

2. Main lube oil service pump failures - #1A, #1B.

3. Attached lube oil service pump failure.

4. Lube oil sump tank - low level.

Group E - Auxiliary Failure

1. Bilge - high level - individual indication for the engine room.

2. Lube oil purifier failure.

3. Lube oil filter - high differential pressure.

* These alarms are similar to Group A alarms but are actuated by a different set of limits on the monitored parameter.

# CHAPTER IV

# BOILER CONTROL SYSTEM

## GENERAL

Automatic control of the boilers requires a complete dynamic analysis of existing steam generator installations to determine necessary basic information concerning the characteristics and capabilities that can be expected from the boiler system to be automated and its supporting auxiliary equipment. Some of this basic information necessary in the design of this control system is:

1. Boiler steam and water flow requirements, boiler drum level limitations and pressure limits for the boilers at all operating loads.

2. Boiler firing rates at any boiler load.

3. Forced draft blower limitations and combustion air supply requirements at any boiler load.

4. Fuel oil pump characteristics and fuel oil flow requirements.

5. Feed water pump characteristics and feed water supply requirements and availability including the deaerating feed tank.

6. Stack gas temperatures and compositions at all operating conditions.

The boiler dynamic analysis will determine the parameters to be used in the computer control system and the characteristics of the automatic control system components necessary to insure optimum response of the boiler system to the steam flow requirements of the propulsion plant, auxiliary systems and hotel services. At the same time, the system must include features that insure the safe and efficient operation of all equipment.

Automatic control of the boilers will be accomplished by the introduction of a combustion control system under computer control. The functions provided by this system are:

1. Control of the air supply to the boilers.

2. Control of the fuel supply to the boilers.

3. Maintenance of the proper fuel to air ratio.

4. Control of the steam pressure.

5. Control of the feedwater supply to the boilers.

6. Control of steam dumping, steam relief and/or burner sequencing.

In order to provide the control and regulating functions, several system inputs and outputs to and from the computer are necessary. The common system inputs to the control system are:

1. Steam pressure in the main steam header.

2. Main engine trip or blocking orders.

3. Throttle control orders.

Inputs are also necessary from each boiler. These inputs are:

1. Fuel oil supply pressure.

2. Forced draft differential pressure between the inlet register and the fire box.

3. Boiler water level.

4. Boiler water mass.

5. Stack gas oxygen content.

Common outputs are required to position steam dump or steam relief valves. Outputs to each individual boiler would control the following functions for that boiler:

1. Position the fuel oil flow control valve.

2. Control the flow of forced draft air.

3. Position the feedwater flow control valve.

4. Control burner sequencing.

5. Actuate alarms.

A general diagram of the proposed combustion control system is shown in Figure 9. The controller inputs and outputs are shown in Figure 10, the controller block diagram.

The control system should be designed so that the system can be readily shifted from automatic to manual control or from manual to automatic control of the boilers and related functions.

The following discussions present the major subsystems for the boiler control system. Each of these subsystems is implemented through a combination of control computer programming and physical sensors and actuators as presented here.

## BOILER CONTROL SYSTEM ELEMENTS

### CONTROL SYSTEM ACTUATORS

A reliable and positive-acting control system should be provided for the actuation of all mechanisms required for the control of the boilers and their auxiliary components. It is proposed that the computer outputs be electrical signals to position solenoid-operated pilot valves. The solenoid pilot valves would port air to diaphragms, pistons, air motors, and other types of devices to position, open, close, or rotate the various components necessary to control the steam pressure and steam flow from the boilers. The existing 150 PSI low pressure air system is considered adequate for control air use. Position indication feedback in most cases

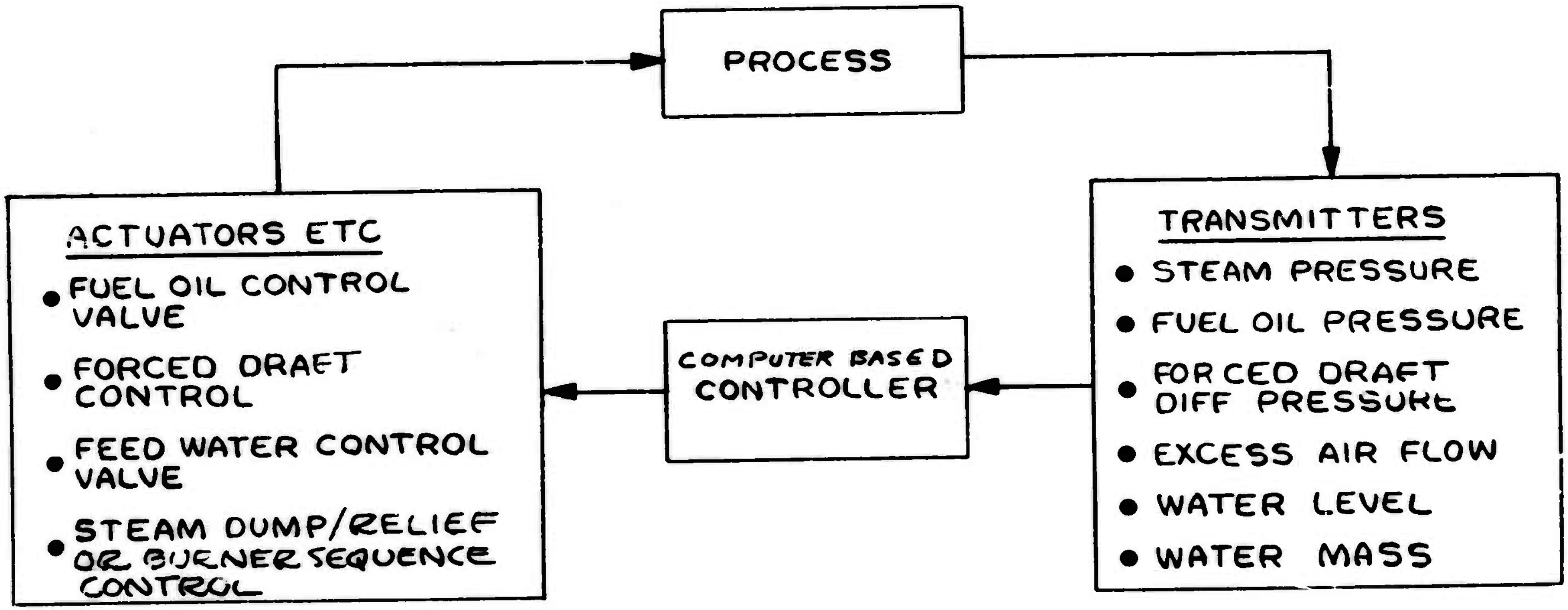



FIGURE 9
COMBUSTION CONTROL-
GENERAL SYSTEM
LAYOUT

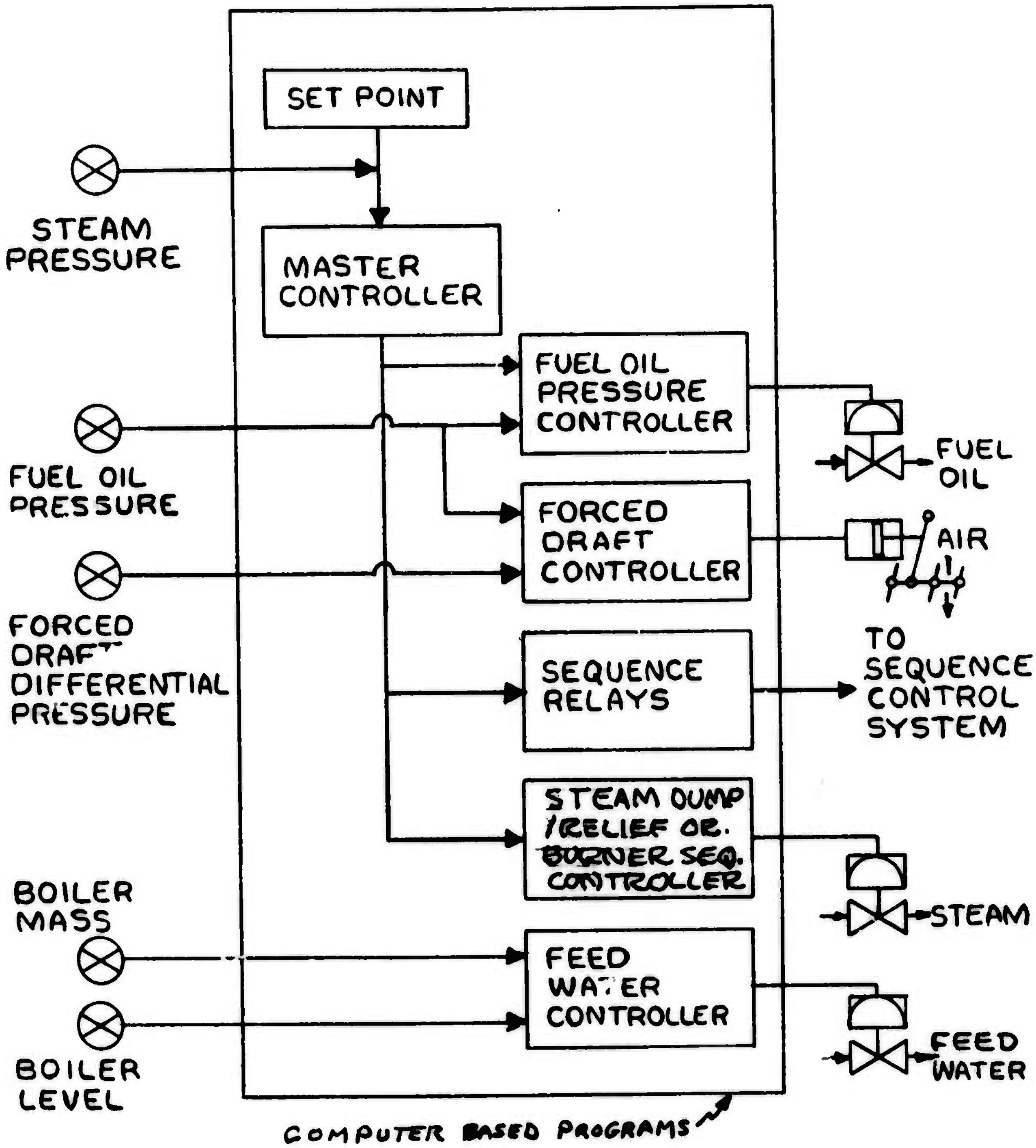



FIGURE 10
COMPUTER BASED
COMBUSTION CONTROL
BLOCK DIAGRAM

can be provided with the use of micro-switches. Hydraulic actuation may be necessary in certain high-load components such as sea-valves.

BOILER FUEL OIL SUPPLY AND TRIP SYSTEM

This system regulates the flow of fuel oil to the active burners of each boiler at the direction of the combustion controller. It further provides for rapid and positive shutdown of fuel oil to the boilers on command from the combustion control system. The proposed fuel oil supply and trip system is shown schematically in Figure 11.

The air-actuated fuel oil flow control valve (Item 1) provides a controlled flow of fuel oil to the active burners under the direction of the combustion controller. When an out-of-limit or casualty condition is detected, and this condition is programmed to initiate a boiler shutdown, the fuel oil flow control valve and the fuel oil safety stop valve (Items 2) automatically close, giving double protection against the introduction of fuel oil to a hot boiler fireside. Individual burner fuel oil valves (Items 3) close under the direction of the burner control system when a no-flame condition is detected by the flame guard system. (Burner control and flame guard systems are discussed in later sections of this Chapter).

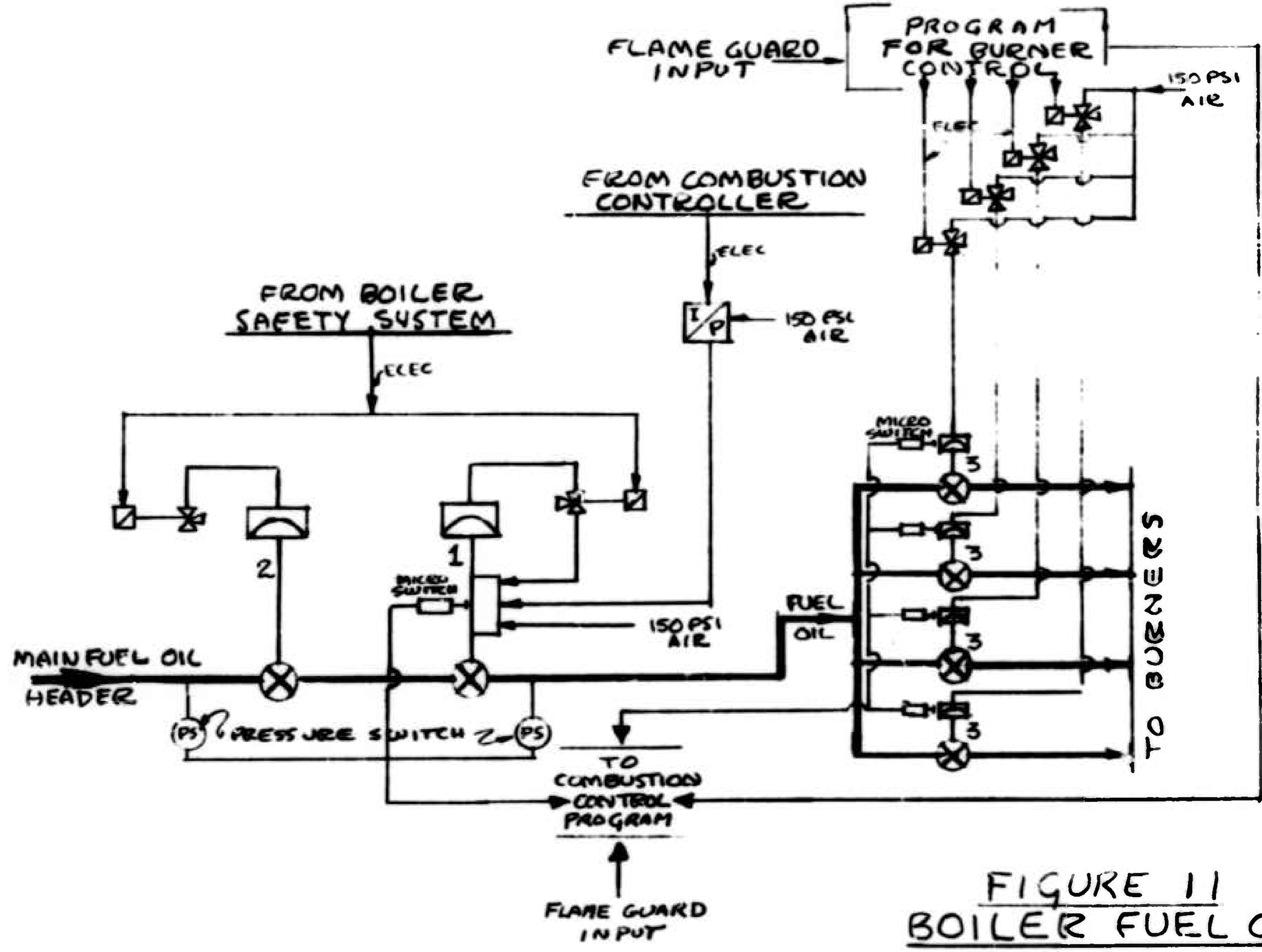



FIGURE 11
BOILER FUEL OIL SUPPLY AND TRIP SYSTEM

## BOILER WATER LEVEL CONTROL

This system provides safe and positive control of the boiler water level, accomodating any transients involved in the dynamic response of the system to normal ship operations and maneuvering. The diagram shown in Figure 12 presents a control system that has been proven to provide safe control at sea with the necessary flexibility to accomodate all normal operating transients. (See SEA SERPENT, Reference (13)).

The feedwater supply to the boiler is controlled by an air-actuated flow control valve (Item 3), one per boiler. Both boiler water level and boiler water mass are sensed using differential pressures across sensor elements. The combustion controller section of the computer program receives input signals from the steam drum water level transmitter (Item 1) and from the boiler water mass transmitter (Item 2). Both signals are used to determine the output signal directed to the I/P transducer (Item 4) which controls the flow of control air to position the feed water flow control valve (Item 3). Items 5 are three-valve manifolds used to equalize pressure across the transmitter diaphragm when the transmitter is being serviced. This system requires periodic blowdown using the blowdown valves (Items 6).

## MAIN STEAM GENERATOR STEAM DUMP, STEAM RELIEF, AND BURNER SEQUENCING SYSTEMS

When low boiler load conditions are encountered with all

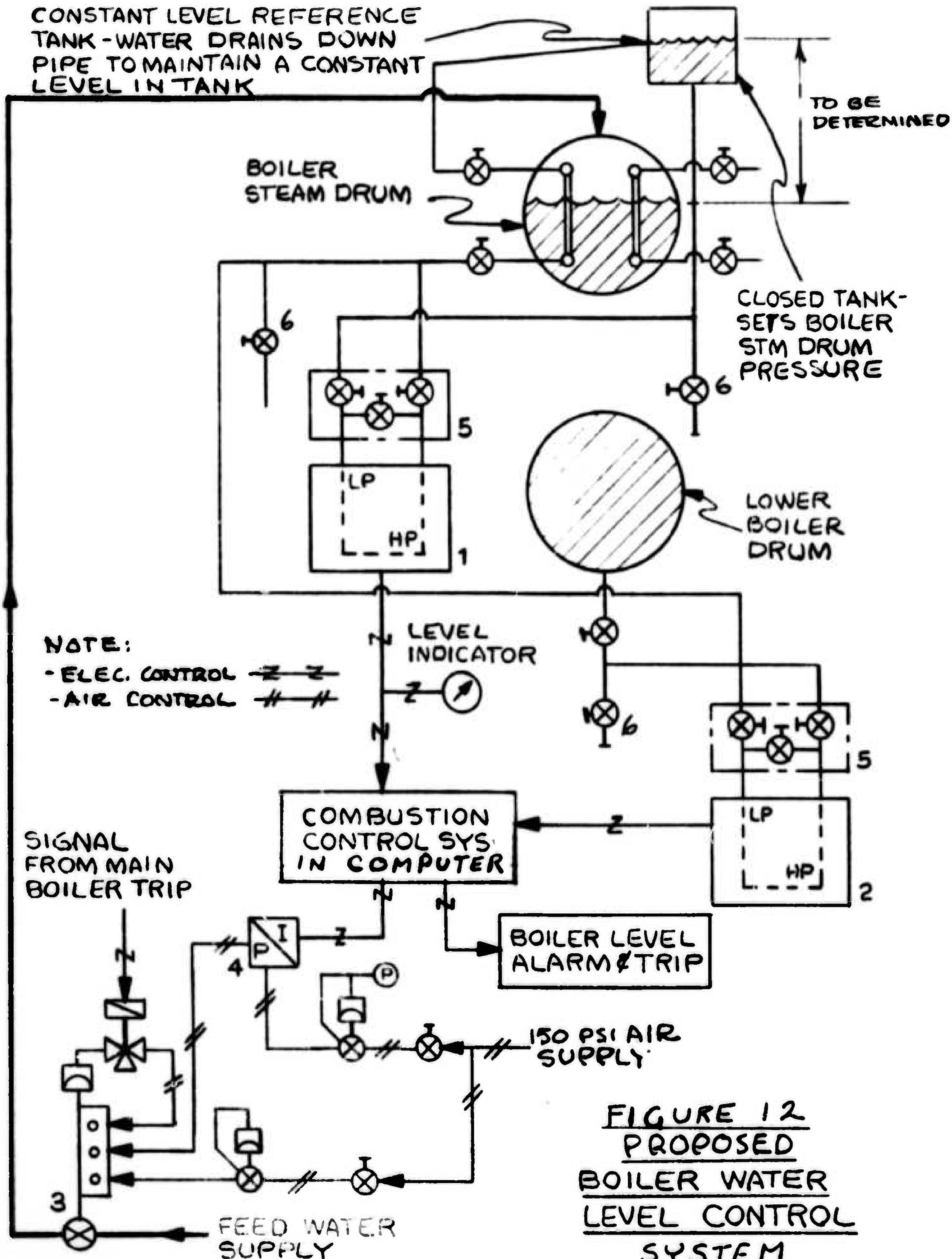



FIGURE 12
PROPOSED
BOILER WATER
LEVEL CONTROL
SYSTEM

burners operating, such as during maneuvering, a means of dumping or relieving excess steam must be included. This excess steam can be disposed of either by dumping it to the main condenser or by relieving it to the atmosphere. The latter approach is less desirable due to the loss of feed water. Long periods of low boiler loads can be handled by provisions for burner sequencing, that is, shutting down one or more but not all of the burners of the active boiler or boilers. The steam dump/steam relief system must be examined carefully to determine the optimum choice considering the cost of modification of the existing system and the impact on plant operation. A sketch of a potential steam dump/steam relief system is presented in Figure 13.

The steam dump or steam relief valve (Item 1) is an air-controlled valve that regulates the disposal of excess desuperheated steam from both boilers. The combustion controller program provides a signal to the I/P transducer (Item 2) which regulates the flow of control air to the positioning mechanism of the steam dump or steam relief valve.

## BOILER FORCED DRAFT AIR CONTROL

Automatic combustion control requires continuous regulation of the forced draft air flow to the boilers to maintain the proper fuel-to-air ratio at any firing rate and to insure optimum operational performance and efficiency. The forced draft air supply can be controlled through either the use of dampers in the air supply ducts to the boilers or by controlling

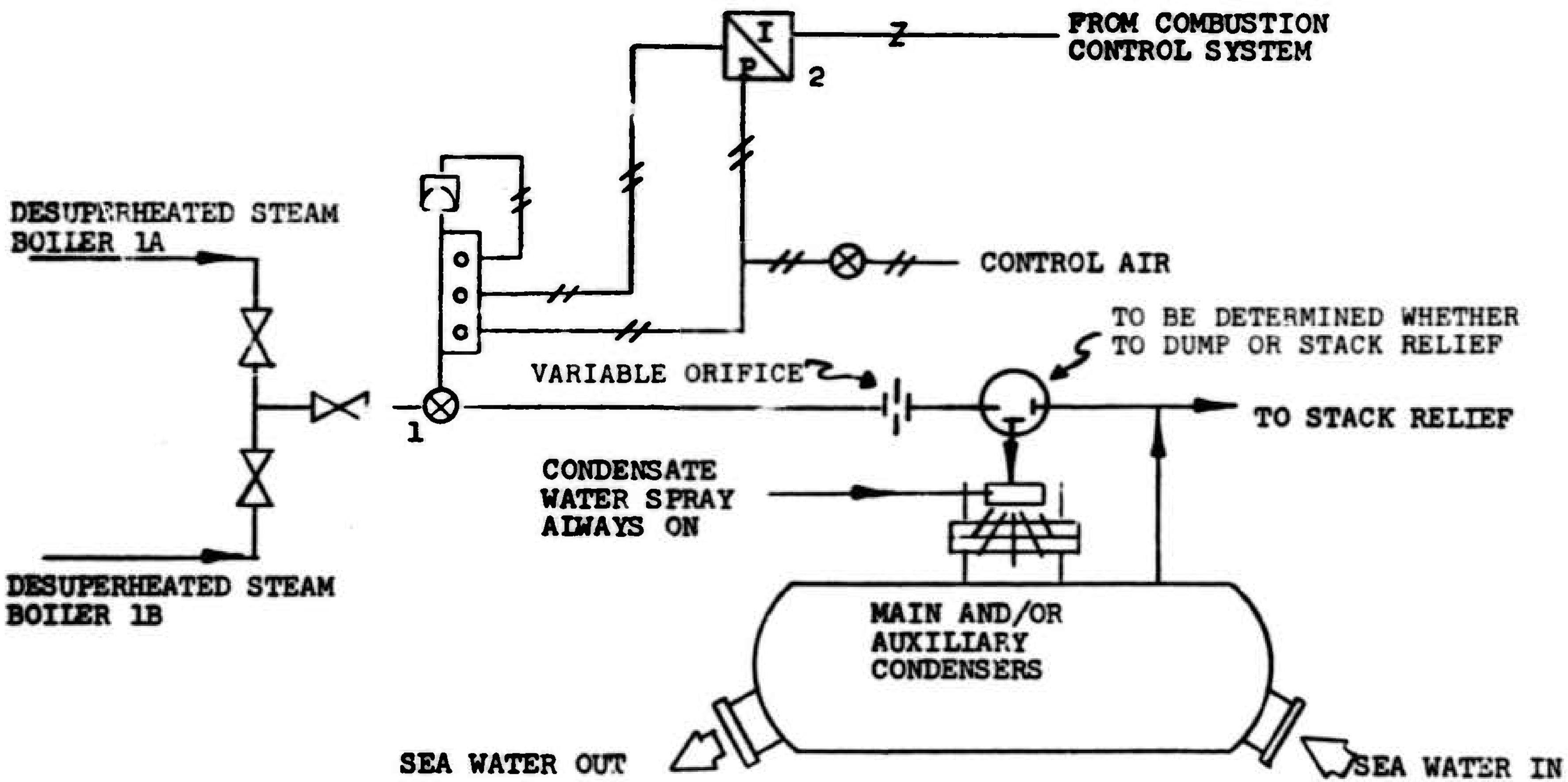



FIGURE 13

MAIN BOILER STEAM DUMP/RELIEF SYSTEM

the speed of the turbines driving the forced draft blowers. If sufficient control of air can be obtained using the present speed governor on the forced draft blower turbines, this approach should be utilized, thus eliminating the need for controlled damper vanes.

Figure 14 presents a sketch of an air control system for a forced draft system. The air differential pressure between the burner inlet register (Point a) and the fire box (Point b) is sensed. A signal indicating this differential pressure is transmitted to the combustion controller program which in turn provides an output signal to a pressure transmitter (Item 2) which supplies control air to the actuator (Item 1) for air duct vanes or the speed control on the forced draft blowers.

Computer monitoring of boiler and turbine related functions will be incorporated into the combustion control system. Several separate systems have been devised to accomplish various monitoring functions insuring safe and efficient operation of the machinery. These systems will be discussed briefly in the following pages.

BOILER SAFETY SYSTEM

This system will monitor all critical components of the system which could, through malfunction or out-of-tolerance conditions, cause damage to a boiler or fail to provide the required steam flow to the propulsive equipment or auxiliary systems. The principal functions of this system are as follows:

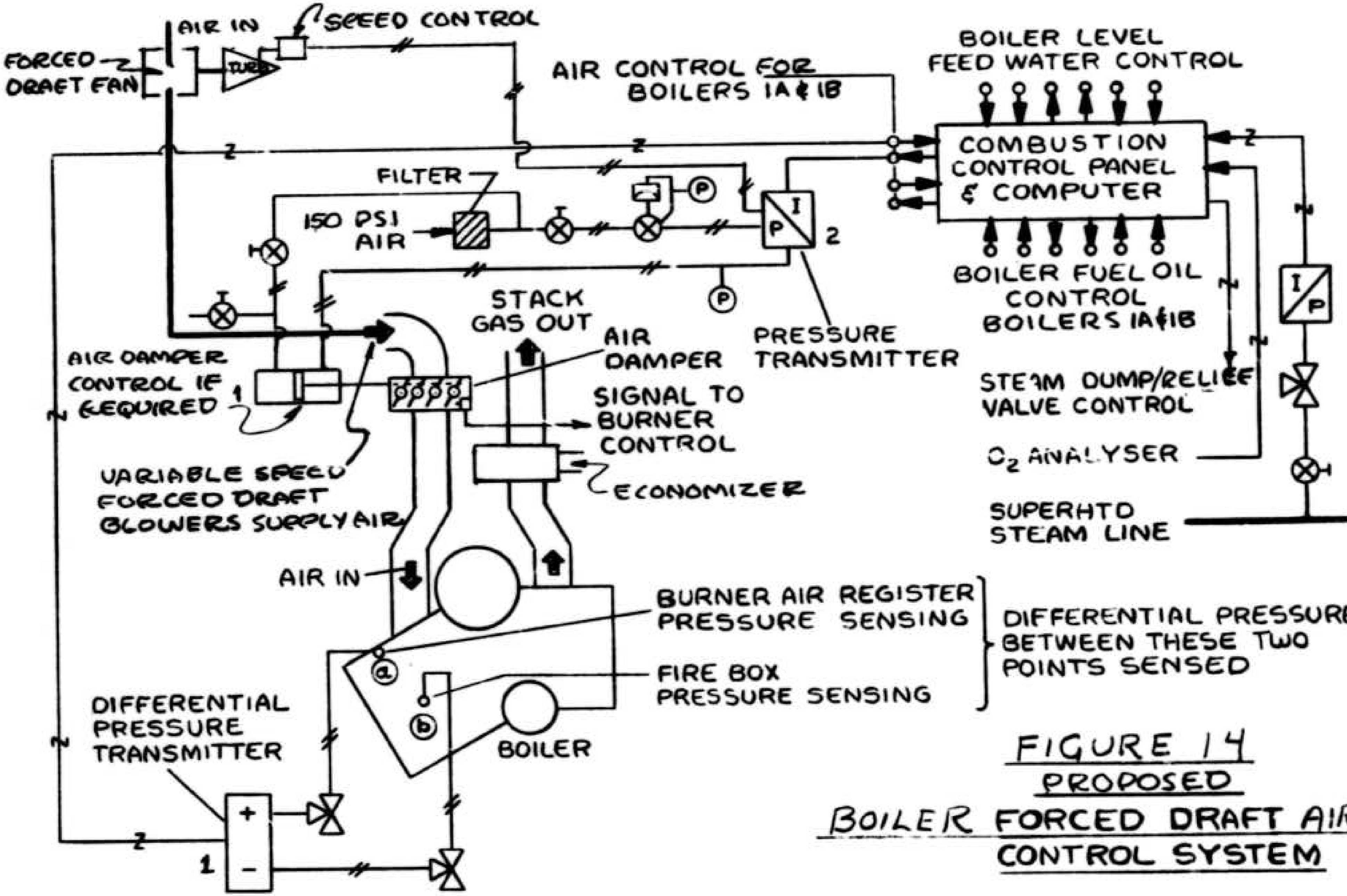



FIGURE 14
PROPOSED
BOILER FORCED DRAFT AIR
CONTROL SYSTEM

1. Monitor boiler water level and compare this level to preset high and low limiting values.

2. Monitor boiler burner flames and distinguish when any one of the four burners in each boiler fire box may be extinguished.

3. Monitor the atomizing steam pressure and compare this pressure with the preset low and high limiting values and with the fuel oil supply pressure.

4. Monitor forced draft air pressure and compare this pressure with preset low limiting values.

5. Monitor the economizer temperature and compare this temperature with a preset high limiting value.

6. Provide a manual trip function which will shut down a boiler rapidly and safely.

7. Provide visual and audible alarms alerting the engineering staff of impending out-of-limit conditions in the boiler system. These threshold limit alarms are:

   a. High or low boiler drum water level.
   b. Low atomizing steam pressure.
   c. Low forced draft air pressure.
   d. High economizer temperature.
   e. Manual trip initiated.

8. Provide alarms, visual and audible, and take automatic shut down and/or corrective action when preset danger limits are reached or exceeded. These alarms and the actions initiated by the computer system are:

   a. Boiler drum water level reaches the high trip level - stop boiler feedwater supply.
   b. Boiler drum water level reaches the low trip level - shut down boiler fuel oil supply.
   c. Forced draft air pressure reaches the low limit pressure - reduce burner firing rate.
   d. Economizer water temperature reaches the high limit temperature - reduce burner firing rate.
   e. Atomizing steam pressure reaches the low limit pressure - reduce burner firing rate.

9. Provide a system test capability for the purpose of simulating out-of-limit conditions to test the functioning of alarms and the initiation of corrective actions without disturbing the operation of the boiler system. This capability shall be included to test the alarms and corrective actions in the event of:

   a. High or low boiler levels.
   b. Low forced draft air pressure.
   c. High economizer water temperature.
   d. Low atomizing steam pressure.

The boiler safety system requires the integration of its functions in the computer with the combustion control system, the burner control system, the flame guard system, and the engineering alarm system. The arrangement and interface areas of these control systems are shown schematically in Figure 15.

To insure reliable operation of the boiler safety system, a second boiler drum level and boiler water mass sensing system shall be included which is completely separated and isolated from the normal level and mass sensing system. This is part of the boiler level alarm and trip system which is shown in Figure 16.

The alarms and corrective actions initiated by the boiler safety system are described in Figure 17.

## FLAME GUARD SYSTEM

This system is an integral part of the boiler safety system. Its functions and features are designed to continuously supervise each burner flame to insure that any burner that should be on-line is in fact ignited. This is accomplished with the use of at least two photo-transistors per burner with adequate sensitivity and discriminating capability to distinguish the failure of any one flame with any or all of the four burners on line. If a burner flame fails, the flame guard system will initiate a warning alarm and provide signals to the combustion control system and the burner control system which will commence burner shut down procedures in a rapid and safe manner. An air wash of the photo cell

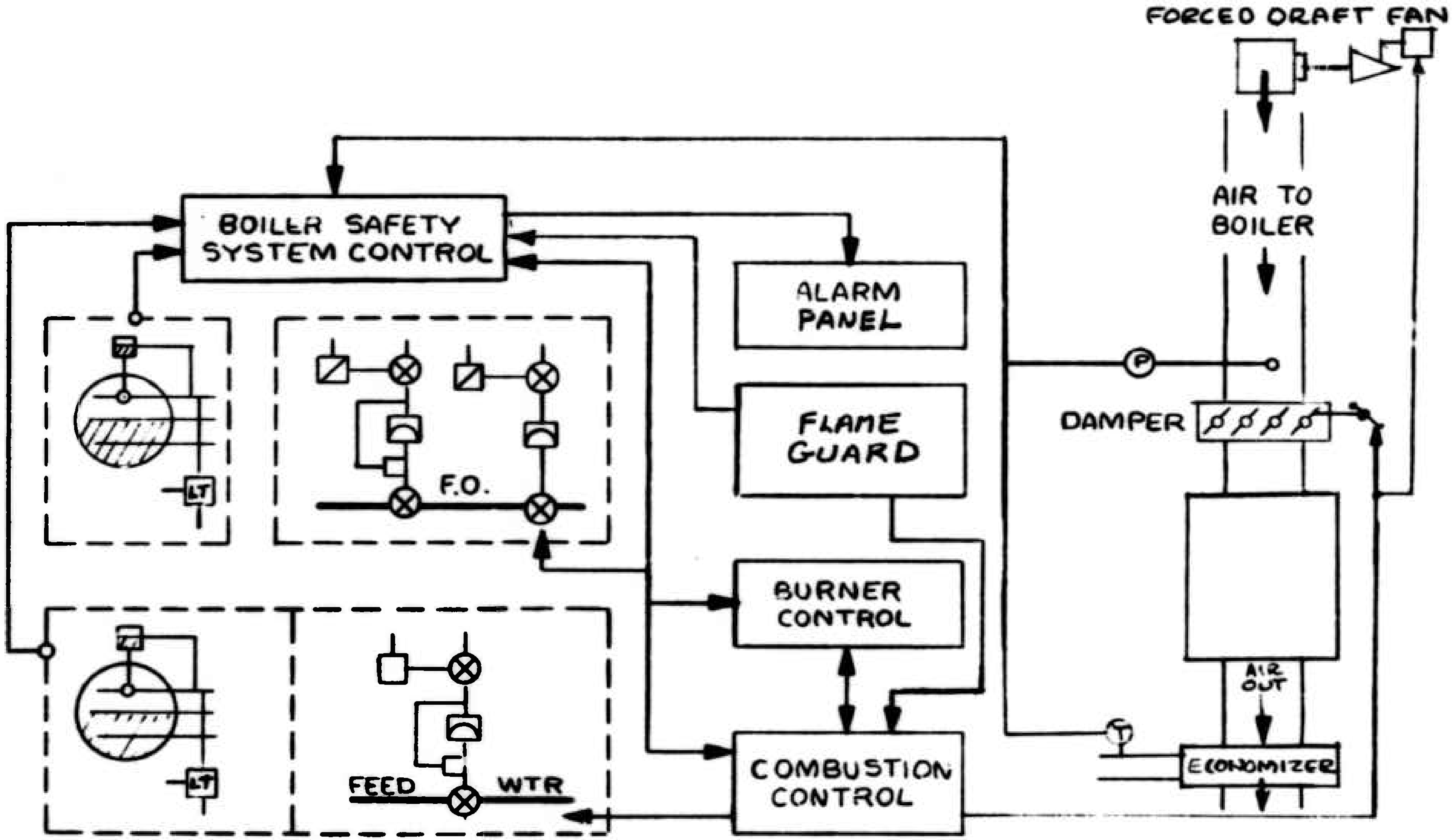



FIGURE 15
BOILER SAFETY
SYSTEM CONFIGURATION

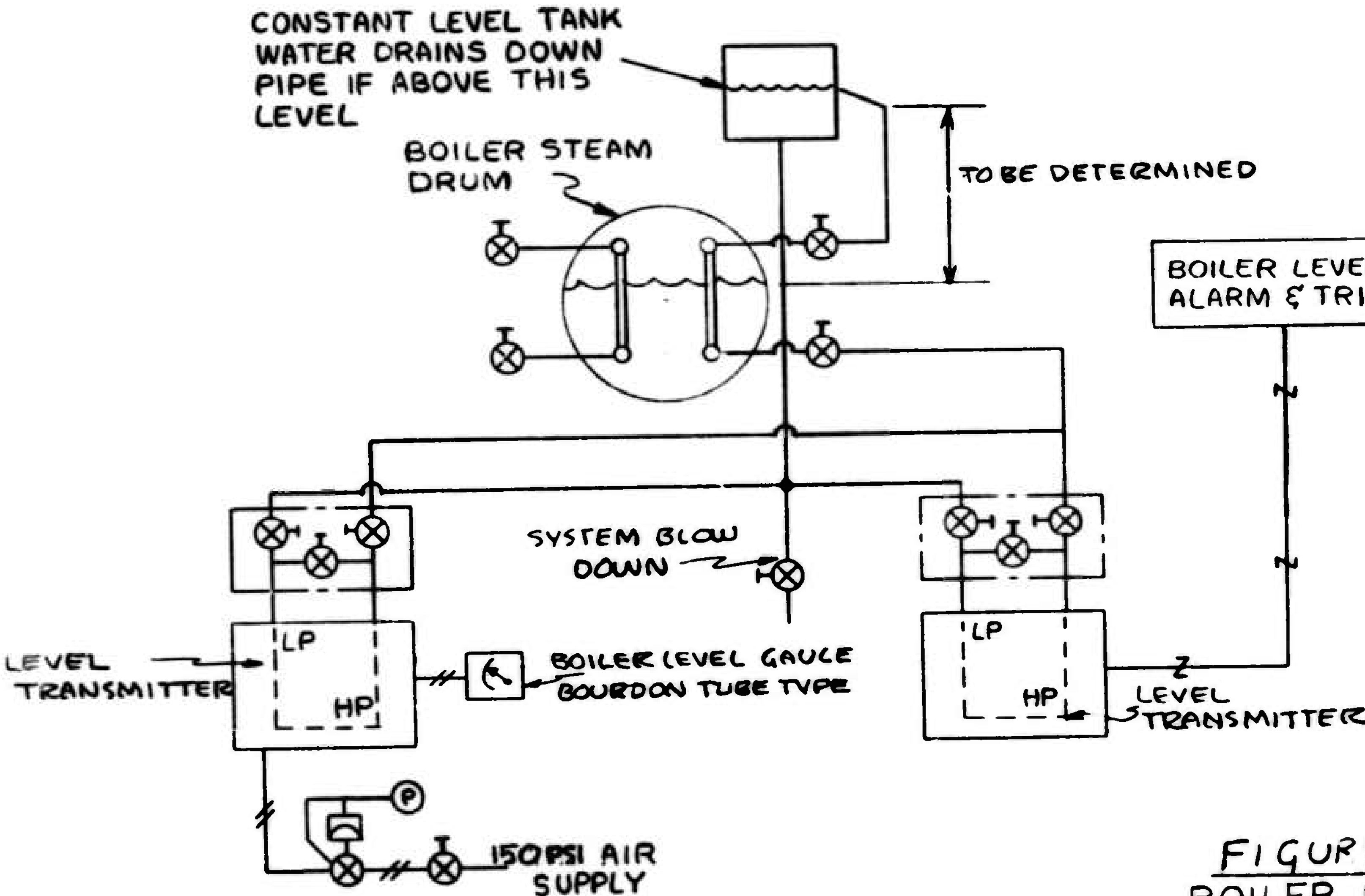
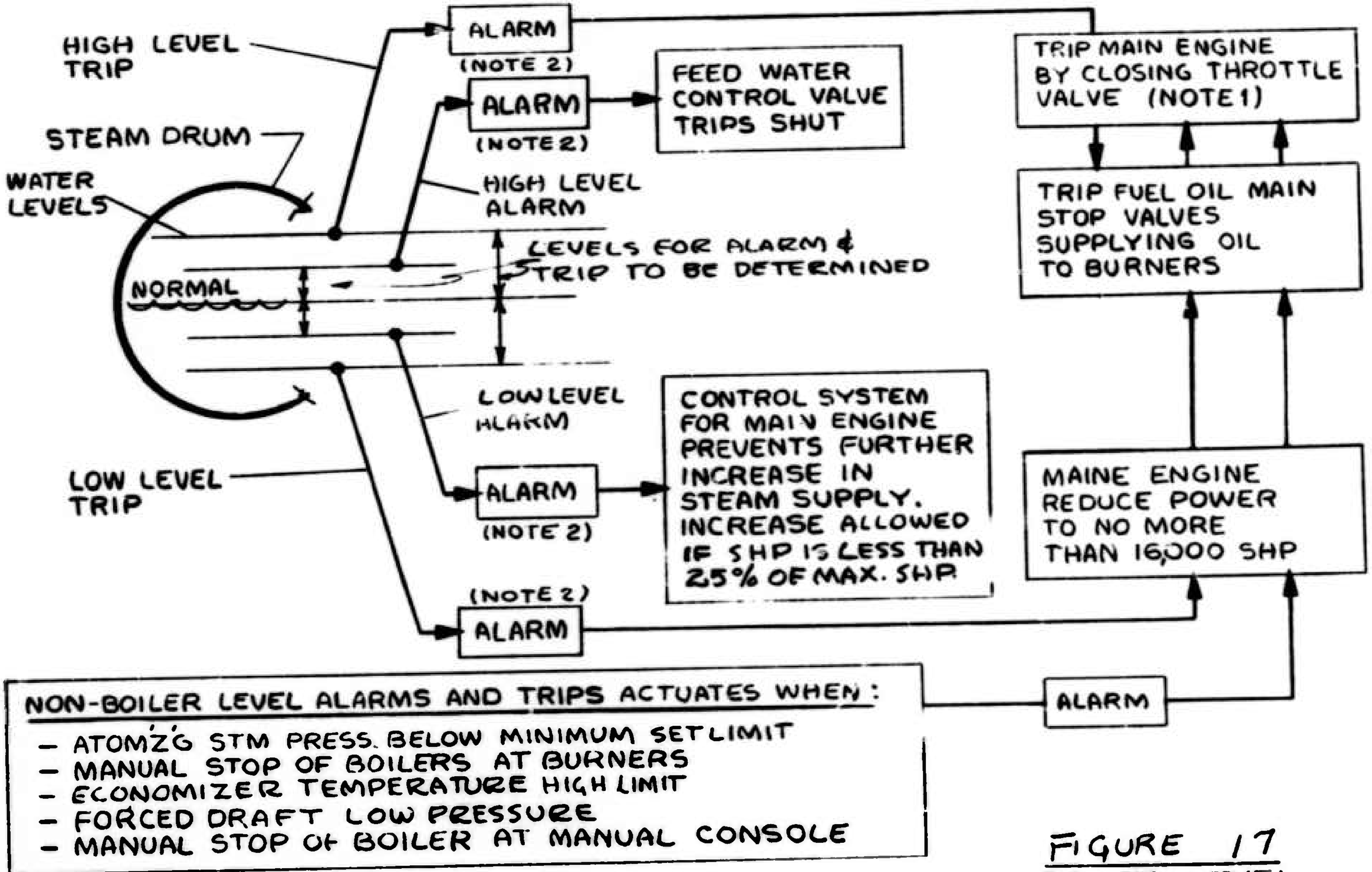



FIGURE 16
BOILER LEVEL
ALARM AND
TRIP SYSTEM




NOTE:
1 — EVENT WILL OCCUR ONLY AT SIGNAL FROM BOTH BOILERS THAT "HI" OR "LO" LEVEL TRIP HAS OCCURRED.
2 — HI & LO LEVEL ALARMS HAVE 10 SEC DELAY AFTER ALARM LEVEL REACHED AND BEFORE ALARM SOUNDS - HI - LO LEVEL TRIPS HAVE 10 SEC DELAY AFTER ALARM SOUNDS & BEFORE RECOVERY EVENTS OCCURS.

FIGURE 17
BOILER LEVEL ALARM AND TRIP FUNCTIONS

faces is included to minimize soot accumulation. Any cell can be removed for cleaning at any time.

A diagram of a flame guard system meeting these specifications is presented in Figure 18. The phototransistor cells mounted adjacent to each burner are shown as Items 1. To permit adjustment for the number of burners in operation, the system includes a sensitivity adjustment which can be made through the control unit, Items 2. When a loss of flame is sensed at any burner, an electrical signal is generated causing a solenoid valve, Items 3, to direct control air to close the fuel oil valve, Items 4, serving that burner.

Automatic control of the boiler plant also requires the provision of automatic control of main auxiliaries functions. Those functions not previously described are discussed in the following sections. Again all control system commands are originated from the computer system.

## FUEL OIL SYSTEM

Unmanned operation of the engine plant requires automatic control of the fuel oil supply to the main boilers. The primary function of this system is to control the pressure of the fuel oil in the discharge header downstream of the main fuel oil service pumps. This can be accomplished using bypass and recirculating lines or by the control of the speed of the fuel oil pumps.

Should low pressure be sensed in the fuel oil supply

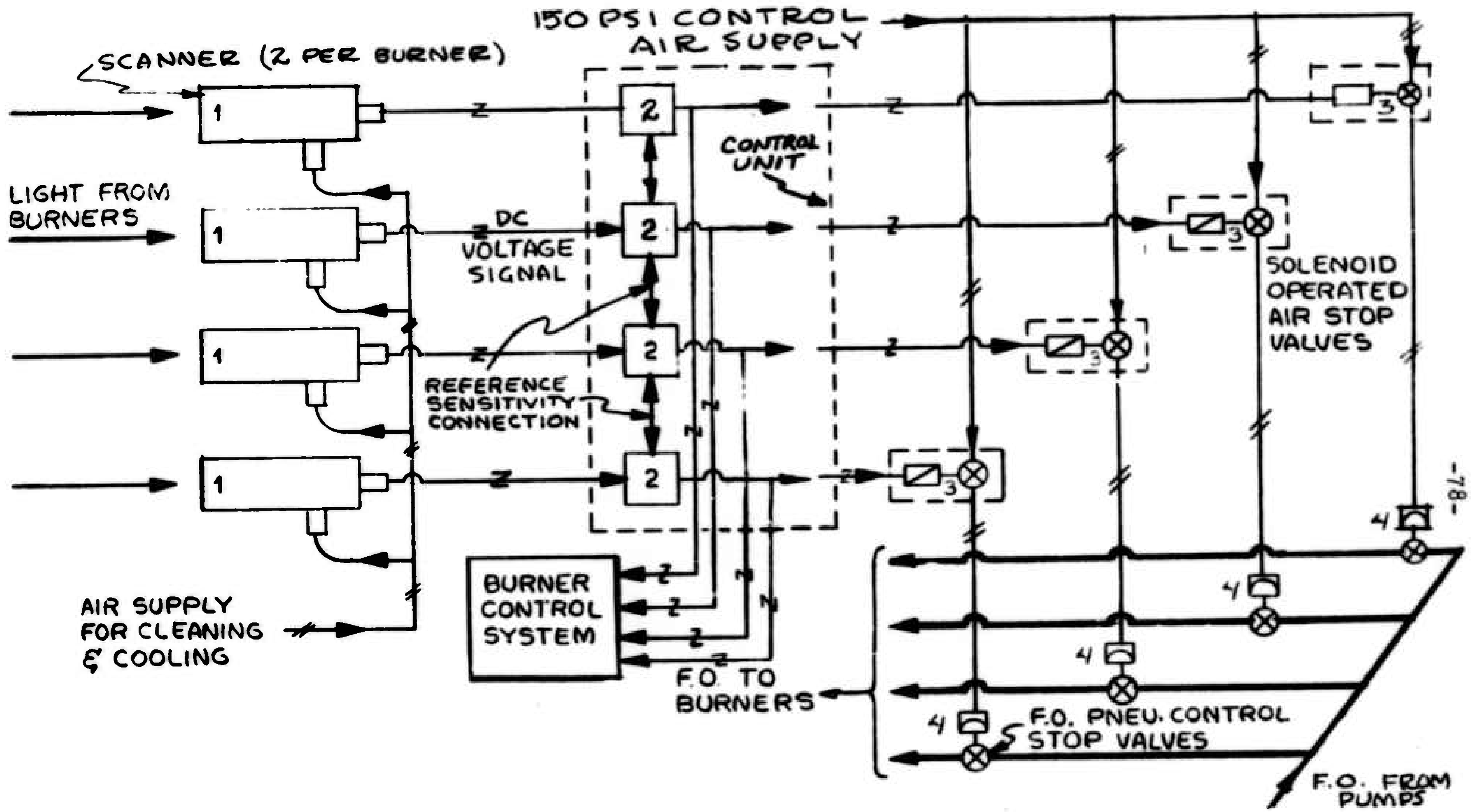



FIGURE 18
FLAME GUARD
CONTROL SYSTEM

discharge header, the stand-by fuel oil service pump will automatically be started. This will also cause the subsequent shut-down of the fuel oil run pump that failed to deliver adequate pressure when the condition was sensed and an alarm will be generated indicating failure of the run pump.

Fuel oils are automatically cleaned using a rotary disc-type filter. The differential pressure across the filter element is continuously monitored and when this pressure reaches a preset high pressure limit, a motor will automatically start, rotating the disc and cleaning the filter element. Should rotation of the disc fail to cause the differential pressure across the filter element to decrease to within prescribed limits, an alarm signal will be initiated.

MAIN LUBE OIL SYSTEM

This system as presently provided is considered satisfactory since it does incorporate automatic start-up of the stand-by lube oil pump on detection of low lube oil pressure at the most remote bearing. Coast down lube oil pressure is provided by an emergency lube oil pump driven by the main propulsion shaft. Alarms and monitors should be incorporated into the system to indicate failure in the system or the start-up of the stand-by lube oil service pump and to monitor the performance and status of the system.

FEEDWATER SYSTEM

This system is designed to deliver adequate feedwater

supply to the main propulsion boilers at any boiler load. Automatic operation of the feedwater system requires that all suction and discharge valves be remotely actuated by the control system so that the system of three main feed pumps can be lined up automatically by the control system for service and emergency use. Either or both of the two potential stand-by pumps can be lined up to draw feedwater from the emergency feed tank or from the deaerating feed tank. Either or both of these stand-by pumps will be started automatically when the main feedwater service pump fails to supply feedwater at the predetermined minimum pressure. The main feedwater pump is automatically shut down in this event and alarms are generated.

Lube oil supply pressure to the feed pumps is sensed and auto-shut-down of the pumps is provided should this lube oil pressure fall below a preset minimum value. Start-up of the stand-by pump is prevented if the lube oil supply pressure is inadequate as indicated by the supply pressure. Alarms are generated should any of these conditions occur.

The existing system has some automatic features that are retained in this proposal for an automatic system. Control of the feedwater pump speed is provided to maintain the proper differential pressure across the feedwater regulator valves. Recirculation of the feedwater flow is also retained to insure adequate pump flow volume at low boiler loads. This capability prevents overheating of the feedwater pumps. When low pressure of the suction header feeding the main feedwater pumps is sensed, the feedwater booster pumps are automatically started.

MAIN CONDENSATE SYSTEM

The existing main condensate system includes an automatic level control for the deaerating feed tank. This control should be retained. A low level alarm should be added to allow corrective action before the level in the deaerating feed tank reaches a value that would require system shut-down.

Continuous monitoring of the condensate hotwell level should be provided. Should this level exceed a preset high value, the stand-by condensate pump will automatically start and the run pump will be shut down, an alarm being generated to indicate the failure of the run pump.

MAIN CIRCULATING WATER SYSTEM

This system provides cooling water to the main condenser at low ship speeds. Start-up of the main circulating water pump is automatic when ship speed drops below 12 knots as measured by the static head at the circulating water inlet to the main condenser. The inlet suction valve to the main circulating pump and the scoop inlet butterfly valve should be power driven under remote control of the computer system to the following positions:

| | Ship Speed | |
|---|---|---|
| | below 12 kts | above 12 kts |
| Main Circ. Pump Suction | open | shut |
| Main Cond. Scoop Inlet | shut | open |

Failure alarms should be provided if the valves do not move in the required directions. This will require micro-switch

indication for both valves in both the fully open and fully closed positions.

AUXILIARY STEAM SYSTEM

The existing set of automatic controls for this system should be retained to control the flow rate and pressure of auxiliary steam serving the following auxiliaries and systems:

1. Atomizing steam for burner firing.

2. Forced draft blowers.

3. Gland sealing.

4. Main fuel oil pump gland cooling.

5. Deaerating feed tank.

MONITORS AND ALARMS

Monitors and alarms should be included to indicate the readiness of the system for operation and to indicate failure of any one of these auxiliaries. The alarms provided for the boiler system, categorized in order of importance to the operation of the propulsive equipment as discussed in Chapter VII, are listed below:

Group A - Main Engine to be Stopped by Computer

1. Loss of main condenser vacuum.

2. Main condenser hotwell - high level.

3. Main boilers tripped.

Group B - Reduced Main Engine Shaft Speed Ordered by Computer

1. Main steam header - low pressure.
2. Main condenser hotwell - high level.*
3. Boiler 1A - high water level alarm/low water level alarm.
4. Boiler 1B - high water level alarm/low water level alarm.
5. Superheater - boiler 1A - high temperature.
6. Superheater - boiler 1B - high temperature.
7. Main condenser vacuum failure.*
8. Forced draft air - low differential pressure.
9. Deaerator feed tank - high level/low level.
10. Feed water - low pressure.
11. Main seawater circulating pump - stopped.
12. Economizer - high temperature.

Group C - Main Boiler Shut Down or Alarm Condition

Individual alarms are to be provided for the following out-of-limit conditions, indicating the cause of the alarm:

*These alarms are similar to Group A alarms but are actuated by a different set of limits on the monitored parameter.

1. Boiler 1A - high water level alarm.
2. Boiler 1B - high water level alarm.
3. Boiler 1A - high water level trip.
4. Boiler 1B - high water level trip.
5. Boiler 1A - low water level alarm.
6. Boiler 1B - low water level alarm.
7. Boiler 1A - low water level trip.
8. Boiler 1B - low water level trip.
9. Forced draft blower failure - individual indication for Blowers 1, 2, 3, 4.
10. Forced draft air - Boiler 1A - low pressure.
11. Forced draft air - Boiler 1B - low pressure.
12. Manual trip - boiler 1A.
13. Manual trip - boiler 1B.

Additional alarms are provided for the combustion system failures. These alarms are:

1. Combustion control system failure.
2. Burner control system failure.

Group D - Main Auxiliaries Failure

Individual alarms are provided to indicate failure in the following components and systems:

1. Boiler 1A stack gas - high temperature.

2. Boiler 1B stack gas - high temperature.

3. Main feedwater pump failure-individual indication for pumps 1A, 1B, 1C.

4. Main feedwater booster pump failure - individual indication for Pumps 1, 2, 3.

5. Fuel oil service pump failure-individual indication for Pumps 1A, 1B.

6. Feedwater pump lube oil - low pressure - individual indication for Pumps 1A, 1B, 1C.

7. Feedwater booster pump lube oil - low pressure - individual indication for Pumps 1, 2, 3.

8. Feedwater - high salinity.

9. Feedwater service tank - low level.

10. Main seawater circulating pump - failure.

11. Main condenser condensate pump failure - individual indication for Pumps 1A, 1B.

12. Exhaust steam system - high pressure/low pressure.

13. Main seawater valves failure - individual indication for each valve.

14. Feedwater drain tank pump failure - individual indication for Pumps 1A, 1B.

15. Main condenser seawater cooling outlet - high temperature.

Group E - Auxiliaries Failure

Individual alarms are provided for auxiliary units or systems indicating the unit or system and casualty condition as follows:

1. Bilge - high level - individual indication for the fire room.

2. Flame guard system failure.

3. Fuel oil filters - high differential pressure.

4. Smoke detector - boiler 1A - high density.

5. Smoke detector - boiler 1B - high density.

6. Boiler safety system failure.

7. Superheater steam - boiler 1A - high temperature.

8. Superheater steam - boiler 1B - high temperature.

## AUTOMATIC LIGHT OFF AND SHUT-DOWN OF BOILERS AND START-UP OF STEAM PRODUCTION

The light-off of burners in large marine-type boilers is a complex and critical task demanding a strict timed sequence of steps to insure safe and efficient start-up of all needed burners. This type of operation is well suited to computer control and supervision. Human involvement in this task requires only the selection of the number of burners to be activated, the remainder of the operation being completed under computer control.

The successful completion of the light-off task requires the sequential check of pre-light-off conditions which are under computer control. If no electric power is available, the diesel generator should be started to supply power to the control system and any other equipment requiring electricity. The pre-light-off conditions to be checked by the computer are as follows:

1. The following auxiliary equipment must be in operating order:

    a. Feed pumps.

    b. In-port use oil service pump.

    c. Light off blower fan.

    d. Sensors and the monitoring system.

2. The following must be closed:

a. 150 psi protection steam system.

b. Superheater and desuperheater stop valves.

c. Blow-off and water wall drain valves.

d. Economizer vents and drains.

e. Fuel oil and atomizing steam valves.

3. The following must be open:

a. Steam drum vent and superheater drains.

b. Atomizing header drains.

Air purge and air flow through the boiler is monitored and timed to insure that any explosive vapors that may be in the system are removed before burner ignition. The fuel oil pump is then started and the recirculation valves are opened with checking for adequate fuel oil flow. A power arc ignition system is automatically inserted into the boiler casing to ignite the burner flame and the air registers for that burner are automatically opened under the direction of the burner sequencing system. Once pre-light-off-conditions are met, the control system ignites the burners using the power arc and the flame guard system monitors these burners to insure safe operation. Other burners are then lit sequentially under the direction of the burner sequencing system.

Once the boiler is on the line and producing steam, the main forced draft blowers, the main fuel oil service pumps and the turbogenerators may be brought on-line, securing the lighting-off blowers and the diesel generator.

The supporting systems for the automatic light-off of boilers are described in the following sections.

POWER ARC BURNER IGNITION SYSTEM

This system is diagrammed in Figure 19. Burner igniters are installed adjacent to all four burners in each of the two boilers. The burner igniters (Item 1) are inserted prior to ignition by means of air-driven pistons (Item 2). The burner control system provides an electrical signal that controls the flow of air to the solenoid-controlled air valve (Item 3) which supplies air to the piston. Ignition will be initiated by the ignition transformer only if the micro-switch (Item 4) indicates the igniter is fully inserted.

BOILER AIR REGISTER CONTROL SYSTEM

This system is diagrammed in Figure 20. Air supply to each burner is controlled by an air register which is withdrawn from the boiler casing creating an open annulus around the burner tip. This annulus admits air from the boiler casing air space to the burners. The register (Item 1) is inserted and withdrawn by two air pistons (Items 2) that are actuated by solenoid-controlled air valves (Items 3). Electric signals from the burner control system energize the valves to properly position the register. Micro-switches (Items 4 and 5) provide signals to the burner control system that the register is open and that the burner rod is inserted and seated in position.

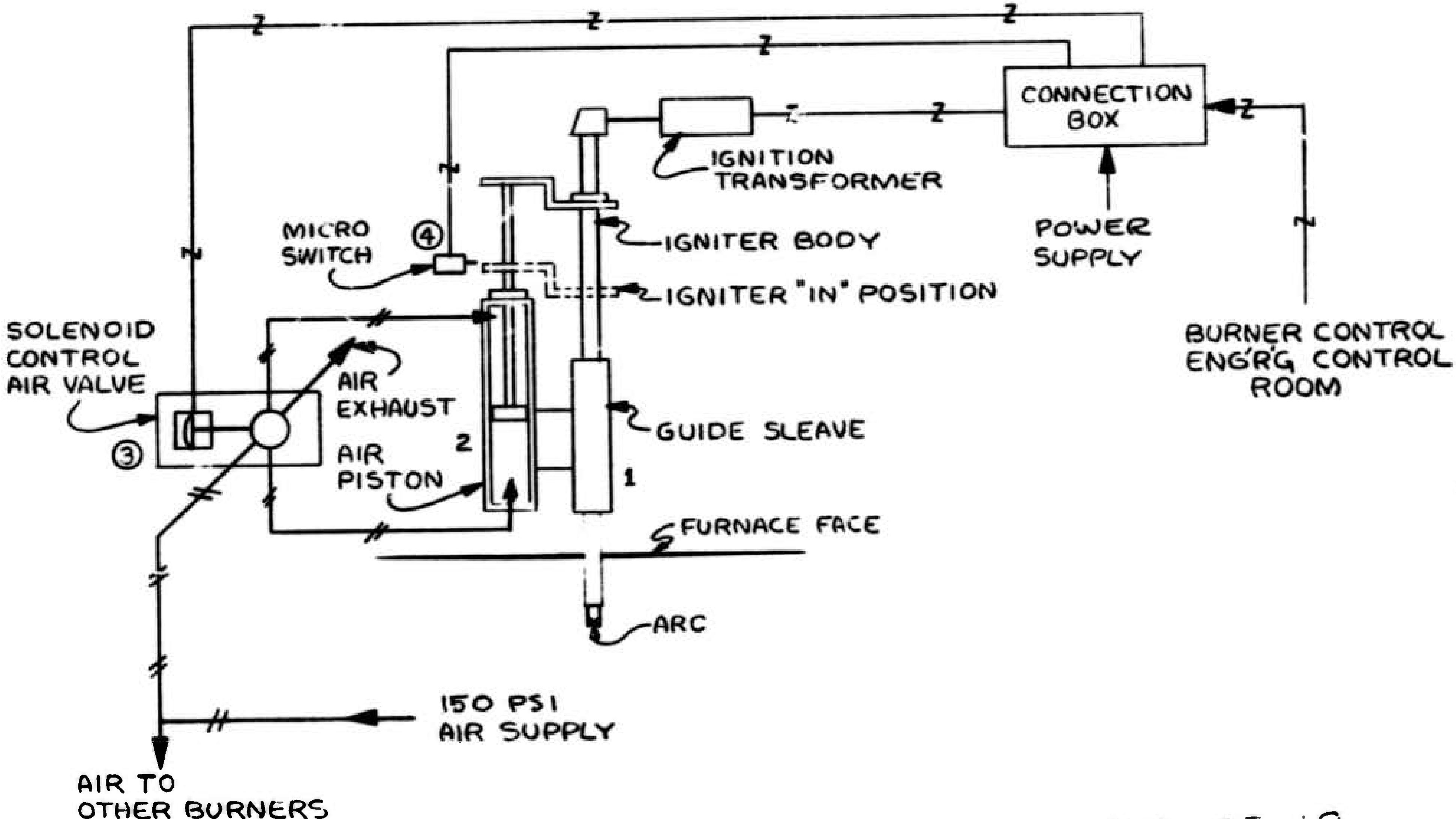



FIGURE 19
POWER ARC
BURNER IGNITION
SYSTEM

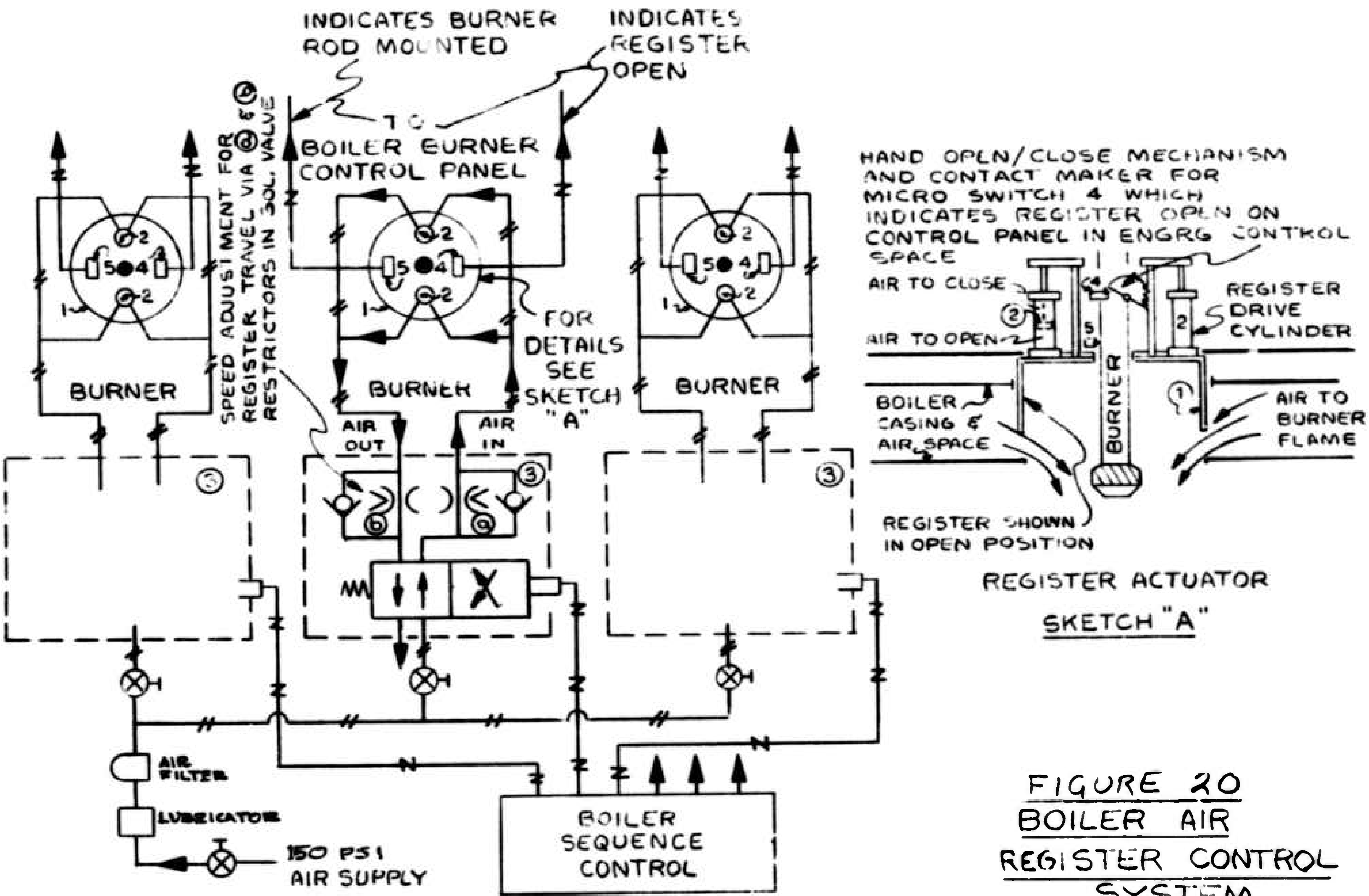



FIGURE 20
BOILER AIR
REGISTER CONTROL
SYSTEM

NOTE: 3 OF 4 BURNERS SHOWN

Shut down of the boilers and steam production is a similar process of timed sequential steps. The fuel oil must be shut off, valves closed, and air purged through the system according to a timed cycle to insure safe and positive shutdown of the burners and the auxiliary systems.

# CHAPTER V

## ELECTRICAL POWER AND AUXILIARIES

The automatic control of the electric power system and other auxiliary equipment is required if the machinery spaces are to be operated in an unmanned condition. Some of the features currently installed on board the ship should be retained and additions or deletions should be made in accordance with the requirements for automatic control.

Narrative descriptions only of the proposed features have been provided here. Detailed schematics or diagrams of circuits and special features to further amplify the concepts involved will require additional engineering study and development. For ease of review the discussion follows closely the information contained in the Ships Information Book, Volume 3, for the DE 1071 Power and Lighting System, (8).

### ELECTRIC POWER SYSTEM

The existing ship service generating system consists of three steam turbine driven generators (450 volts, 60 cycle, 3 phase), one tandem-drive diesel generator (450 volts, 60 cycle, 3 phase), and two ship service switch boards (1S and 2S).

There are some existing automatic features that will be retained under the proposed computer control system. The turbogenerator units are speed controlled by electro-hydraulic

governing systems, one for each unit, maintaining generator speed within limits under varying load and steam supply conditions. Automatic shut-off of steam flow to the turbines is provided in the event of governor failure, overspeed of the turbine, or excessive back pressure in the turbine exhaust system. The voltage is automatically regulated to within one percent of the designed voltage. Manual synchronization capability as is currently installed should be retained under computer control.

The standby diesel driven generator is controlled by an electro-hydraulic speed governing system to regulate the speed of the generator within specific limits under varying load conditions. Overspeed detection and shut-off of the diesel generator is provided should overspeed occur. The voltage is regulated automatically to within one percent of the design voltage.

There are three operating modes currently available in the utilization of the electric generation facilities. All three of these modes should be retained under the proposed computer control system. They are:

1. Turbine generators supply the electric power to the switch boards, the bus tie between boards 1S and 2S, being closed, allowing distribution of turbine generated power from both switch boards. In the event of failure of the turbogenerators, the diesel powered

unit will start automatically, supplying power to vital loads. Automatic transfer between generator supplies, both turbine and diesel generated, and the 2S switchboard is available.

2. In this mode, the turbogenerator supply power to the 1S switchboard and the diesel generator unit supplies power to the 2S switchboard. The bus tie between the switchboards remains open. Only vital loads are supplied power from the 2S board.

3. The third mode of operation is a parallel generation by different power generation units, utilizing the diesel generator and any or all of the turbogenerators. The bus tie between switchboards 1S and 2S is closed.

In addition to the present automatic capabilities in the electric power system, automation of other functions is necessary for a completely unmanned system. These functions are start-up, synchronization and loading, and monitoring as well as casualty response.

Automatic start-up of the turbine-driven generator sets should be possible from a cold turbine condition with automatic sequencing and actuation of the following operations:

1. Drain steam lines.

2. Bleed steam through the lines to warn the lines and supply gland seal steam to the turbines.

3. Open the sea water valves for condenser cooling water.

4. Start the circulating water pump for condenser sea water cooling.

5. Put the condensate pump in an automatic run condition so that the hotwell level can be properly maintained.

6. Open the lube oil supply lines to the turbine and generator bearings.

7. Supply steam to the turbine for warm up and bring to the proper run speed with no load.

8. At each step the system will be automatically checked for proper initial pressure, temperature, and level conditions before that step is executed. This prevents damage to or improper operation of the turbogenerator units.

9. A vibration monitor will be provided to continuously check vibration amplitude against preset limits. Excessive vibration will cause automatic shut-down of that turbogenerator unit.

The above automatic start-up of turbogenerator units will bring the sets to run speed at no load in a reasonable period of time, allowing for a safe and reliable start in every instance. The control system should allow manual start up of the turbogenerator sets from a remote location such as the engine room control center.

With a generator set at run speed and in a no load condition, the control system shall be capable of automatically loading and synchronizing all on line generator sets. Existing controllers, bus ties, and switch gear will require modification to provide this capability. Bus tie breakers should be remotely actuated from the engine room control center for a rapid selection and implementation of any one of the three control modes discussed above. Switch gear must be remotely actuated to allow computer direction of loading in the event of a system casualty or breakdown. Manual operation capability should be provided for all breakers and switches.

Automatic monitoring of all electric power system mains and major branches should be provided to detect and automatically isolate faults, bring alternate power supply sources online, and drop low priority loads from service as required to maintain the power demand within the available supply limitations. The existing transfer arrangements will be retained as a minimum capability. However, an analysis of the power system must be performed to determine power panels and services

that should be provided as an alternate source of power supply and those that should have the capability of automatic transfer of power supplies in the event of a power system failure.

There should be no provision for parallel operation of turbine or diesel powered generator sets and shorebased power.

The existing casualty power system should be studied to determine the need for retention of this system in view of the flexibility and redundancy of the automated electric power system. An analysis of the time available to manually rig casualty power cables under modern battle damage scenarios should be undertaken to evaluate the need for this system when considered in light of the automatic electric power system that will be available to support casualty control functions.

The existing ship service 400 cycle power motor generator sets providing 100 kw from each of the two sets should be retained along with some of their automatic features that are presently provided. Voltage regulation to within ± 0.5 percent at the rated input will be retained along with frequency regulation to within ± 0.5 percent at the rated input. The present motor controller should be retained with overload and low voltage protection. The line voltage balancer should be retained, holding voltage variations to within one percent under no load and unbalanced load conditions. The current voltage and frequency monitors will continuously sense the voltage and frequency output of each motor generator set and provide signals to the automatic system when preset limits are exceeded.

Additional automatic functions should be provided to fully automate the 400 cycle electric power system. Automatic monitoring of all 400 cycle mains and branches should be provided to detect and isolate faults. The standby motor generator set will be brought on-line automatically to pick up the load without interruption of power supply to loads not affected by the fault. In the event of failure of the run motor generator set as determined by comparison of voltage and frequency outputs with preset limits, the standby unit will be started automatically and the failed unit will be shut-down automatically.

## AUXILIARY SYSTEMS

Certain major auxiliary systems not directly involved in support of the main propulsion plant will require automation. These systems are:

1. Bilge pumping system.
2. High pressure air compressors.
3. Ship's service air compressors.
4. Distilling plants.
5. Air conditioning plants.
6. Refrigeration plant.

Certain automatic features apply in general to each of the above systems and should be provided where necessary.

Before starting any system, a check should be made of critical system functions and support systems. This may include cooling water pressure, lube oil pressure, valve alignment, etc. to insure a safe and efficient start of the system. Manual prestart alighment is satisfactory where automatic start-up is not required or if the equipment is used infrequently.

Where automatic start-up of standby components is needed, the pre-start check shall include automatic actuation of all valves and equipment necessary in the operation of the standby equipment. This may include lube oil valves, feed valves, etc.

When all system pre-start checks have been made and all equipment has been determined to be in proper starting alignment or condition, the system will be brought on line in properly sequenced steps to insure a safe and reliable start in each instance. Monitoring of system parameters during normal operation will be provided, comparing output, temperatures, pressures, etc. against preset limits. When limits are exceeded, alarms will be generated automatically and after a suitable pre-determined time delay, the control system will take corrective actions automatically. This may include a reduction in power or output or, where required, system shutdown to avoid serious damage to components.

The provision of automatic shut-down of components or systems will require remote automatic actuator operation. The shut-down procedure will follow a series of sequential operations that will safely and rapidly take the component or system to a fully inoperative condition. Alarm indicators will be provided to alert personnel and the automatic control system when the shut-down is complete. Details of the alarms and casualty recovery actions are presented in Chapter VI.

# CHAPTER VI

## ALARMING, AUTOMATIC CASUALTY RESPONSE AND/OR AUTOMATIC BLOCKING OF MACHINERY PLANT FUNCTIONS

### INTRODUCTION

A capability to provide computer monitoring of machinery plant functions with provision for automatic casualty response and/or automatic blocking would permit maximum necessary propulsion power and maneuverability while minimizing the potential damage to the propulsion or auxiliary system components due to out-of-limit or casualty conditions. Alarms and automatic blocking functions necessary for this purpose are discussed in the following sections.

### ALARM GENERAL REQUIREMENTS

The machinery alarm system should incorporate the following methods and locations of indication and acknowledgment:

1. Visual lighted indication of an alarm condition.

2. Audible horn, buzzer, and bell indication of an alarm condition.

3. Grouping of all important alarm indicators in a single panel located in the engine room control center. Alarms within this panel should be grouped

to indicate the importance of the alarms to the operation of the propulsion plant.

4. Provisions for silencing audible alarms once corrective actions have been initiated. The lighted indicators will remain on until the out-of-limit or casualty condition has been corrected.

5. Provisions for transmission of alarm indication to other areas of the ship. This will alert duty personnel, bridge watch, engineering officers, and others to an alarm condition. The indications and locations are:

   a. Bridge - visual lighted and audible signals indicating the specific alarm group involved.
   b. Duty Engineer's Stateroom - visual lighted and audible alarms indicating the alarm group involved.
   c. Engineering Officer's Stateroom - visual lighted and audible signsls indicating alarms of major importance in high priority groups and only group alarms for lower priority occurances.
   d. Engineering Log Room and Ward Room - visual lighted and audible signals indicating the alarm group involved.

e. Throughout the Engineering Spaces - audible and flashing signals to alert duty engineering personnel of needed action.

The alarms should be grouped into the following categories, indicating the level of importance of the alarms to the operation of the propulsion plant:

| Group | Alarm Category |
|---|---|
| A | Main Engine Stopped. |
| B | Reduce Main Engine Shaft Speed. |
| C | Main Boiler Shut-down. |
| D | Main Auxiliaries Failure. |
| E | Auxiliaries Failure. |
| F | Miscellaneous Alarms. |

Each group must be subdivided to indicate alarm location in either the engine room or boiler room since there is no direct access between these two spaces. The alarms for each of these spaces are also presented in Chapters III and IV.

The duty engineer should be equipped with a remotely actuated radio signal unit that can be attached to the belt. This unit will provide an audible signal in the event of an alarm or casualty condition. This signal will request his presence in the engine room control center to identify the nature of the alarm and take corrective action.

## ALARMS AND CASUALTY/OUT-OF-LIMIT MONITORING

The specific alarms to be provided and the conditions that initiate those alarms are listed below. They are presented in accordance with the alarm groupings presented immediately above.

### Group A - Main Engine to be Stopped by Computer

The individual alarms listed below indicate those conditions for which the main engine will be stopped i.e., the turbine throttles are directed to go to fully closed due to an abnormal condition. Alarm panels with individual indicators should be provided to indicate the cause of each condition. These alarm indicators are:*

1. Loss of main condenser vacuum - B.
2. Main shaft axial displacement beyond limits - E.
3. HP turbine overspeed / LP turbine overspeed - E.
4. HP turbine rotor axial displacement beyond limits - E.
5. Main lube oil - low pressure - E.
6. Main condenser hotwell - high level - B.

* The symbol, E, indicates that this alarm is located in the Main Engine Room Control Center. The symbol, B, indicates location in the Boiler Room Control Centers and, A, an auxiliary or electrical function located in Electrical Center.

7. Main boilers tripped - B.

8. Astern turbine exhaust steam - high temperature - E.

9. HP turbine - excessive vibration - E.

10. LP turbine - excessive vibration - E.

11. Turning gear engaged - E.

12. Manual trip of the engine - E.

13. Idling cycle failure - E.

14. Main engine emergency stop from the bridge or from the engine room control center - E.

<u>Group B - Reduced Main Engine Shaft Speed Ordered by Computer</u>

Individual alarms are provided to indicate the casualty or out-of-limit condition which should result in automatic reduction and limitation of the main shaft speed. These alarms and the causes for their actuation are:

1. Main steam header - low pressure - B.

2. Lube oil to main engine - low pressure* - E.

3. Lube oil to main engine - high temperature - E.

* These alarms are similar to Group A alarms but are actuated by a different set of limits on the monitored parameter.

4. Main condenser hotwell - high level* - B.

5. Boiler 1A - high water level/low water level - B.

6. Boiler 1B - high water level/low water level - B.

7. Superheater - boiler 1A - high temperature - B.

8. Superheater - boiler 1B - high temperature - B.

9. Astern turbine exhaust - high temperature* - E.

10. Main condenser vacuum failure* - B.

11. Forced draft air - low differential pressure - B.

12. Deaerator feed tank - high level/low level - B.

13. Feed water - low pressure - B.

14. Main seawater circulating pump - stopped - B.

15. Bearings - main reduction gears and turbines - high temperature - E.

16. Economizer - high temperature - B.

Group C - Main Boiler Shut Down or Alarm Condition

Individual alarms are provided for the following out-of-limit conditions, indicating the cause of the alarm:

* These alarms are similar to Group A alarms but are actuated by a different set of limits on the monitored parameter.

1. Boiler 1A - high water level alarm - B.

2. Boiler 1B - high water level alarm - B.

3. Boiler 1A - high water level trip - B.

4. Boiler 1B - high water level trip - B.

5. Boiler 1A - low water level alarm - B.

6. Boiler 1B - low water level alarm - B.

7. Boiler 1A - low water level trip - B.

8. Boiler 1B - low water level trip - B.

9. Forced draft blower failure - individual indication for blowers 1, 2, 3, 4 - B.

10. Forced draft air - boiler 1A - low pressure - B.

11. Forced draft air - boiler 1B - low pressure - B.

12. Manual trip - boiler 1A - B.

13. Manual trip - boiler 1B - B.

Additional alarms are provided for the combustion system failures. These alarms are:

1. Combustion control system failure - B.

2. Burner control system failure - B.

Group D - Main Auxiliaries Failure

Individual alarms are provided to indicate failure in the following components and systems:

1. Bridge throttle control system failure - E.
2. Boiler 1A stack gas - high temperature - B.
3. Boiler 1B stack gas - high temperature - B.
4. Diesel generator failure - A.
5. Main feed water pump failure - individual indication for pumps 1A, 1B, 1C - B.
6. Main feed water booster pump failure - individual indication for pumps 1, 2, 3, - B.
7. Fuel oil service pump failure - individual indication for pumps 1A, 1B, - B.
8. Main lube oil service pump failure - individual indication for pumps 1A, 1B - E.
9. Attached lube oil service pump failure - E.
10. Feed water pump lube oil - low pressure - individual indication for pumps 1A, 1B, 1C - B.
11. Feed water booster pump lube oil - low pressure - individual indication for pumps 1, 2, 3 - B.

12. Feed water - high salinity - B.

13. Lube oil sump tank - low level - E.

14. Feedwater service tank - low level - E.

15. Main seawater circulating pump failure - B.

16. Turbogenerator condensate pump failure - individual indication for pumps 1A, 1B, 1C - A.

17. Turbogenerator circulating pump failure - individual indication for pumps 1A, 1B - B.

18. Main condenser condensate pump failure - individual indication for pumps 1A, 1B - B.

19. 150 psi air system - low pressure - A.

20. Exhaust steam system - high pressure / low pressure - B.

21. Turbogenerator lube oil - low pressure - individual indication for units 1A, 1B, 1C - A.

22. Turbogenerator windings - high temperature - individual indication for units 1A, 1B, 1C - A.

23. Main seawater valves failure - individual indication for pumps 1A, 1B - B.

24. Feedwater drain tank pump failure - individual indication for pumps 1A, 1B - B.

25. Diesel generator seawater service pump failure - A.

26. Turbogenerator condenser - vacuum failure - A.

27. Voltage/frequency failure - A.

28. Main condenser seawater cooling outlet - high temperature - B.

Group E - Auxiliaries Failure

Individual alarms are provided for auxiliary units or systems indicating the unit or system and casualty condition as follows:

1. Distilling plant failure - individual indication for plants 1, 2 - A.

2. Bilge - high level - individual indication for the engine room, fire room, and auxiliary machinery space 1 - A.

3. Air conditioning plant failure - individual indication for plants 1, 2 - A.

4. Lube oil purifier failure - E.

5. Flame guard system failure - B.

6. Lube oil filters - high differential pressure - E.

7. Fuel oil filters - high differential pressure - E.

8. Smoke detector - boiler 1A - high density - B.

9. Smoke detector - boiler 1B - high density - B.

10. Boiler safety system failure - B.

11. Superheater steam - boiler 1A - high temperature - B.

12. Superheater steam - boiler 1B - high temperature - B.

Group F - Miscellaneous Alarms

All non-critical alarms should be indicated on the cathode ray tube output units only. Such alarms will display the nature and cause of the alarm and any other necessary information.

## GENERAL ALARM CONCEPTS

The entire alarm system will be referenced to the main twin mini-computer system located in the log room. Information concerning the nature and cause of any active alarm, time of initiation, and any further information can be stored in the computer memory. Personnel can access any of this information through the cathode ray tube display units. This method of alarm information storage allows flexibility in the number and content of alarm indications and minimizes the space and hardware necessary for complete and reliable condition monitoring of the ship's machinery.

Each system or component to be monitored must undergo a

detailed analysis to determine the limits at which alarms will be initiated. This analysis will also yield information concerning advanced warning of a potential casualty condition allowing the engineering personnel to take corrective action before a critical or potentially damaging situation occurs. An example of such a multi-level limit is the boiler water level alarm and trip system exhibited in Figure 12.

Automatic alarms and automatic corrective action are beneficial to the operation of the engine plant since it allows a reduction in power levels rather than a complete shutdown of all power under casualty conditions. This type of corrective action provides a responsive system even under most casualty conditions.

The simplicity of the alarm system is maintained at a maximum by monitoring only the principal function of the equipment being monitored. An example of this would be the criterion used for evaluating the failure of a pump by measuring the discharge pressure and comparing it to pre-set normal pressure levels.

## AUTOMATIC BLOCKING SYSTEM

As a result of certain casualty conditions, it is necessary to block the normal mode of operation of the propulsion system if the engine plant is to maintain some measure of responsiveness during casualty conditions. Limitations and restrictions must be placed on the operation of the engine to

insure that the equipment will not be damaged as a result of the casualty condition with improper command decisions for the condition of the machinery. In the event of auto-blocking by the computer, visual and audible alarms should be provided at the bridge throttle control station and at the engine room control center throttle control location, warning personnel that the engine plant is in an auto-blocking mode. Indication should also be provided on the cathode ray tube display units indicating the reason for the auto-blocking. In the event of a combat or other overriding external factor, the responsible officer must have the facility for overriding this auto-blocking function with the attendant risk of permanent damage to the propulsion equipment.

Conditions for which auto-blocking should be invoked and limitations placed on the propulsion system due to these conditions are listed below:

1. Low boiler level (initial low level alarm). Reduce and limit output of the propulsion plant to below a predetermined level (i.e., 50% of the maximum available power output).

2. High or low level boiler trip (second high or low level alarm). Further reduce and limit output of the propulsion plant to no more than a second predetermined level (i.e., 30% of the maximum available power output).

3. Low main steam pressure (first low pressure alarm). Permit no further increase in propulsion plant power output.

4. Low main steam pressure trip (second low pressure alarm). Reduce and limit output of the propulsion plant to a predetermined level (i.e., 50% of the maximum available power output).

5. Shaft speed transmission failure. Hold the present power output level.

6. Engine order telegraph transmission failure. Hold the present power output level.

7. Ahead turbine pressure transmission failure. Hold the present power output level.

8. Astern turbine pressure transmission failure. Hold the present power output level.

# CHAPTER VII

## DAMAGE AND CASUALTY CONTROL

### GENERAL

Examination of the manning situation on a naval warship indicates that one of the major functions that requires the assignment of manpower is that of damage and casualty control when operating under a general quarters condition. For example, on a DE 1052 class ship approximately 94 men must be held available during general quarters to handle damage and casualty problems. These men do not perform useful work or man required operating stations unless there is in fact damage or a casualty that requires their services. Automation of damage and casualty control functions therefore, can produce a significant reduction in the number of men that must be assigned to naval warships.

Except for the automated fire main and pumping system, descriptive diagrams are not included in this analysis. It is considered that the narrative description provided does adequately outline the concepts involved and that preparation of detailed diagramatics or schematics of the special features presented will require undertaking the analysis and investigative actions discussed herein.

Determination of the degree of automation and what damage

control functions should be automated requires two actions. First, an in depth analysis should be performed of battle damage sustained during World War II and later actions, by ships of this or similar classes that are being considered for automation. The analysis should categorize damage inflicted, the type of weapon or action that caused the damage, the damage or casualty recovery action taken, and the end result of recovery actions. The analysis should also include an in depth review of major casualties not associated with battle actions such as fire, flooding, collisions, etc., the cause of the casualty, the recovery actions taken, and the end result of the recovery action. Results of this analysis should then be carefully examined and modified as required to reflect potential battle damage effects that could be inflicted by present day and near future weaponry and battle techniques. The study results would form the basis for a determination of the extent and type of automated damage control that should be provided and establish the reduction in manpower that might be achieved through automation in this area. Second, a thorough examination and investigation of modern and developmental damage and casualty control equipment, systems, and techniques should be conducted to establish their capabilities, effectiveness and potential for use in a automated damage control system for a naval warship. The results of this investigation should be compared to the requirements developed above to establish the overall system characteristics and features for a given ship.

Without the detailed analysis and investigative actions outlined above it is not possible to identify and describe a complete automated system. However, certain features can be outlined based on available information. The following will serve as examples of functions or approaches that should be considered in providing a naval warship with an automated damage control capability:

1. Fire warning and control system utilizing inert gas smothering system for major compartments.

2. Automated fire main and pumping system incorporating isolation loops and flexibility in system line up.

3. Remote indication of status of main watertight compartments and remote quick closing of watertight doors and major openings in watertight bulkheads and decks.

4. Improved interior communications system to facilitate damage and casualty control actions.

Provision of the above automated features could result in a significant reduction in the number of personnel that must be assinged to a naval warship to satisfy damage and casualty control demands. A brief discussion of each of the above features is provided below.

## FIRE WARNING AND CONTROL SYSTEM UTILIZING AN INERT GAS SMOTHERING SYSTEM FOR MAJOR COMPARTMENTS

A fire warning and control system would be an essential and critical requirement when a naval warship is automated to the extent that major compartments and areas of the ship are totally unmanned for long periods of time. Compartments in non-automated ships that would normally be manned with watch-standers on a continuous basis must now be left without working or watch personnel to warn of the presence of smoke or fire and to initiate fire control action. Recent developments in industry and in commercial shipping make it entirely feasible to accept the unmanned compartment concept without increased risk, and in many instances with less risk than now prevails. It is considered that developments in the following two areas should be thoroughly examined and a selection of equipment and systems be made as a required and essential ingredient of the automated ship concept.

### FIRE WARNING SYSTEM

Extensive developmental work has gone forward in an effort to market equipment and systems that have a high level of sensitivity to detect, at a very early stage, smoke generated by an incipient fire, and heat, beyond normal limits, produced by a fire. The components and systems produced as

a result of this effort are available and have been demonstrated in service to be reliable and certain in their ability to detect and announce, via various types of alarms, the presence of smoke and fire in an unoccupied room or compartment. The proliferation of equipments and systems in this field is well documented providing a large array from which a selection can be made that would be most suitable for a naval ship installation. Selection of a system should include consideration of the following specific features:

1. Equipment will be designed and tested to MILSPEC requirements for shock, spray tightness, vibration resistance, etc.

2. The system should monitor compartment atmosphere for the presence of smoke and for temperature and initiate an alarm when levels exceed preset threshold values.

3. Sensing units shall be small and compact allowing distribution of units within a large compartment such that incipient fires can be detected in localized areas.

4. The system and each sensing unit should be capable of being tested for operability by means of a simple smoke sample and temperature check. Ability to bypass any fire control reaction, built into the system while making system tests, should be available.

5. Central smoke and fire alarm panels should be provided in either or both the damage control center and the engine room control center with indicators for each sensor locating the sensor within the compartment where more than one sensor is installed.

6. Local alarms, audible and flashing lights, should be provided within each compartment served giving a general compartment alarm that will warn personnel who may be present in the compartment.

7. Automatic activation of suitable fire control facilities (i.e., inert gas smothering, sprinkling, flooding, etc.) should be provided after a suitable time delay (delay is based upon studies of the particular compartment, flammable materials present, fire control equipment fitted, etc.). This time delay should provide, where possible, an opportunity to investigate an alarm and initiate local manual fire control avoiding the activation of a massive fire control response, which could cause damage and immobilize needed ship functions unnecessarily.

INERT GAS SMOTHERING

Worthwhile advances have been achieved in the field of fire control through the use of smothering techniques. New inert gas systems have been developed which will effectively

extinguish an active fire while not harming personnel present or requiring that they evacuate the compartment involved. These systems have a very real advantage over earlier systems where fire control was achieved through massive use of foam, water sprinkling, or $CO_2$ smothering, causing damage to installed equipment or requiring immediate evacuation of a compartment by all personnel. These techniques required a significant recovery time once initiated, even where the fire was small, and could result in a critical immobilization of ship functions. A proposed inert gas smothering system should include the following features:

1. Use of an inert gas that can be carried in sufficient quantities to handle complete smothering of an active fire in a major compartment such as the engine room or fire room. The location of gas storage should be flexible with delivery to the affected compartment via a piping system if required. Trade-off studies should be conducted to determine optimum volume of inert gas needed and storage location for the gas.

2. The gas should effectively smother an active fire while at the same time minimize the danger to personnel from exposure to the gas, thus allowing a reasonable exposure time to permit very localized fire fighting (i.e., to remove oil rags, use of $CO_2$ directly on an electric motor fire, etc.). It is understood

that an inert gas with the trade name, "HAYLON", and a Du Pont product, FE-1301, have the characteristics described.

3. Release of the gas to the compartment involved should be possible either by manual local, manual remote from the damage control central or the engine room control center, or automatically by the fire sensing and alarm system. The latter case should only occur following a suitable time delay as discussed above.

4. Gas release nozzles should be distributed in a large compartment such that they are adjacent or in the approximate vicinity of the fire/smoke sensors. These latter have the ability to activate the release of gas only from the nozzle adjacent to the sensor that detects a smoke or fire situation. General release of gas to the entire compartment should be possible by local or remote manual means or when two or more sensors in a compartment are triggered.

## AUTOMATED FIRE MAIN AND PUMPING SYSTEM INCORPORATING ISOLATION LOOPS AND FLEXIBILITY IN SYSTEM LINE-UP

The ability to remotely activate large valves, sense line pressures, start and stop large pump units, and provide multiple piping loops can materially improve the fire fighting capability and effectiveness of a ship's fire main system, and at the same time reduce the numbers of personnel that must be

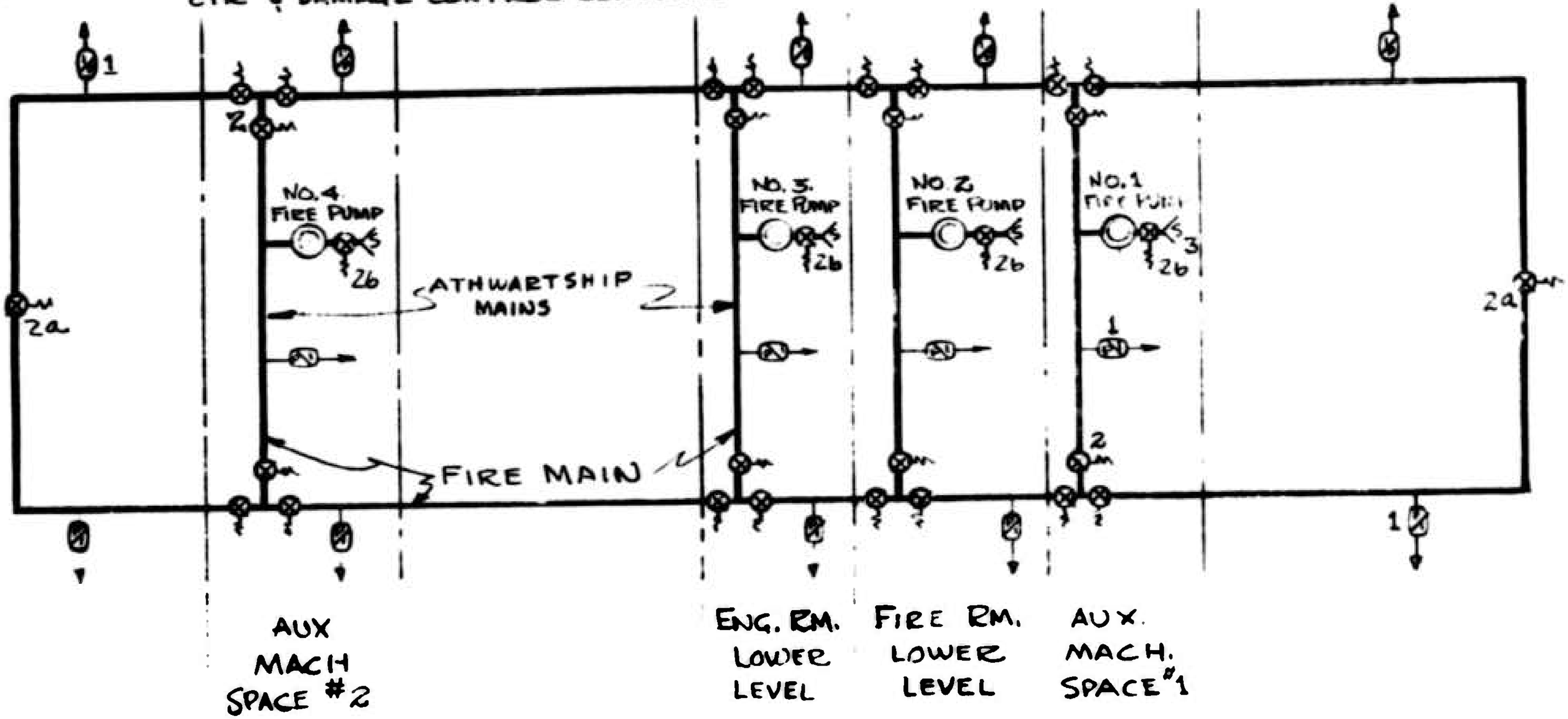
held in readiness for possible fire fighting services. It is proposed that the fire main system include the following principal features as described below:

FIRE MAIN LOOPS

Existing fire main piping arrangements should be modified to provide a port and a starboard fire main tieing together at the bow and stern as shown in Figure 21. Each pump (4 total) would remain in the compartment in which it is currently located and would supply salt water via athwartship mains to the port and starboard mains. Three remotely operated valves, Items 2, would be provided at the points of connection of the athwartship mains to the port and starboard mains. This arrangement, with the addition of two remotely operated valves, Items 2a, at the point of connection of the port and starboard mains at the bow and stern, would permit isolation of any pump while retaining all of the port and starboard main service, or isolating any damaged section of the main without losing the entire main. Closing remote stop valves, Items 2b, together with the remotely operated valves at the ends of the athwartship mains permits isolation of lines that could, through a rupture, flood a compartment from the sea. Pressure transducers, Item 1, to sense fire main pressure at the discharge of each pump and in each isolatable section of main would be required to sense a rapid drop in pressure signifying loss of a pump or major damage to the pipeline. The transducers would

FIGURE 21

3 — SEA SUCTION
2 — REMOTE ACTUATED STOP VALVES - OPERATED FROM ENG. RM CONTROL CTR AND DAMAGE CONTROL CENTRAL
1 — PRESSURE TRANSDUCER - PROVIDES SIGNAL (NORMAL/LOSS OF PRESSURE) TO PANEL IN ENG RM. CONTROL CTR & DAMAGE CONTROL CENTRAL




NOTE:
- THIS IS INTENDED AS A SIMPLIFIED DIAGRAM - NO ATTEMPT HAS BEEN MADE TO SHOW ALL VALVES, RISERS, ETC THAT WOULD BE REQUIRED BY THE FINAL DETAIL DESIGN OF THE SYSTEM

PROPOSED SCHEMATIC OF THE AUTOMATED F[illegible]E MAIN SYSTEM

provide an alarm signal at the fire main/pump status panel located in damage control central and would provide a signal to the control circuits to automatically stop the defective pump and isolate the segments of the main via the closure of the remotely operated valves. This system would provide for actuation of all remotely operated valves and start-up of the fire pumps from either damage control central or the engine room control center. It is estimated that this system would require a total of 30 remotely operated valves and 14 pressure transducers.

Consideration should also be given to the injection of synthetic polymers (non-Newtonian fluids) into the fire main system at each fire pump to significantly increase the rate of flow of water through the mains when required. Injection of polymer would be accomplished by remote activation of the polymer system from the fire main control panels on decision of damage control personnel. Since supply of polymer would be limited, its use would be restricted to critical fire situaitons where maximum water rates was essential.

## REMOTE INDICATION OF STATUS OF MAIN WATERTIGHT COMPARTMENTS AND REMOTE QUICK CLOSING OF WATERTIGHT DOORS AND MAJOR OPENINGS IN WATERTIGHT BULKHEADS AND DECKS

Survival of a naval warship in flooding situations is dependant upon the ability of the ship and crew to achieve maximum confinement of the flooding through the use of water

tight subdivisions, by rapid dewatering, and/or by counter-flooding where accurate information is available regarding the extent and location of the flooding. In an automated ship, where minimum personnel are available for battle damage recovery and control, maximum use must be made of remotely controlled quick closing devices, accurate and rapid dissemination of flooding data, and remote and automatic control of high volume dewatering devices. The capacity, size, number of units, speed of operation of devices and equipment involved should be determined on the basis of the war damage analysis and study effort discussed at the outset of this Chapter. The various functions and concepts to be considered in this area are outlined below.

## REMOTE INDICATION OF STATUS OF MAIN WATERTIGHT COMPARTMENTS

To provide positive and rapid indication of the states of all major opening in watertight bulkheads and decks, openings (i.e., doors, hatches, scuttles, bulkhead ventilation valves, etc.) should be fitted with micro switch indicators to provide a signal to a central damage control panel, located in damage control central, when closures are, in fact, closed. A closure in any other position than the fully closed position would be shown on the panel by a red light indicator. When fully closed a green indication would be shown. This would compare to the submarine "green board," indication when all hull openings are closed. This panel would provide a clear

and continually updated picture to damage control personnel monitoring the status of the ships watertight integrity.

Indications should also be provided of flooding conditions in main water-tight compartments using bilge flooding alarms and water level measuring devices (pressure transducers or capacitance type gages) located at the forward and aft ends of large compartments. Readouts of bilge flooding and water levels should be available on the damage control panel located in damage control central.

## REMOTE QUICK CLOSING OF WATERTIGHT DOORS AND MAJOR OPENINGS IN WATERTIGHT BULKHEADS AND DECKS

To provide for rapid containment of flooding, automatic quick closing devices, capable of being actuated remotely, should be provided for doors, hatches, scuttles, ventilation valves, sea water valves, etc., that forms a portion of the closure boundary for watertight subdivisions and the ship's hull. Development of mechanisms to trip doors and hatches from open to shut are required, together with power driven dogging devices to provide a positive watertight seal. Suitable alarms, audible and flashing light, in the vicinity of remotely operated doors and hatches would be required to warn personnel of imminent closure action, and reasonable spring loadings and dash pot devices should be fitted to minimize the possibilities of personal injury when the closures are activated remotely. Hand override of closures should be possible to permit access of damage control personnel to compartments.

Since rupture of large sea water lines internal to the ship's hull can provide a major source of flooding remotely activated quick closing sea water valves should be fitted at the point of penetration of the ships hull (i.e., hull valves). Ability to activate these valves should be provided from the engine room control center and/or damage control central with indication of valve position provided in both of these control areas. Valve activation, timing, and closure concepts would be similar to that provided in the sea water systems of all modern deep diving U.S. Navy submarines.

High capacity dewatering equipments should be fitted with the capability of remote starting from damage control central. Relatively lightweight gasoline engine and gas turbine driven high speed/high capacity pumps are available that would materially enhance survivability of the ship under a flooding situation if such pumping capacity could be brought to bear rapidly after flooding is detected. Control of depth of flood water in a compartment would provide damage control personnel the opportunity to fit temporarily closures to bring flooding under control.

## IMPROVED INTERIOR COMMUNICATION SYSTEM TO FACILITATE DAMAGE AND CASUALTY CONTROL ACTIONS

Communications is a critical element of damage control. Existing systems require that a relatively large number of personnel be assigned phone talker duties to provide this

service. When so engaged men are not available for other duties directly related to damage control recovery actions. If personnel were provided a communication system that allowed mobility then the need to assign phone talkers and the risk of misunderstood orders passed by word of mouth under high stress conditions would be avoided. Wireless communication systems have been developed that provide the possibility of a short range reliable system that would allow every member of the damage control party to be fitted with an ear plug receiver and throat mike, giving each individual the ability to communicate with each other and with damage control central while at the same time allowing complete physical mobility to directly undertake damage control actions. Such direct and positive means of communication with and between damage control personnel can be of vital importance in the light of the high noise levels that frequently prevail when involved in battle recovery actions.

# CHAPTER VIII

# THE BRIDGE SYSTEM

## GENERAL

As mentioned in the Preface and in Chapter II, the Bridge System reported here is due to Messrs. Gerald P. Moe and Steven P. Rogers of Human Factors Research Incorporated, Goleta, California, (See Reference (1)) and was developed by them for the Naval Ship Research and Development Center, Annapolis, Maryland. This is one of several different designs for this function which could have been presented here. Most of the remaining material in this Chapter is taken selectively from Reference (1 which contains much more detail than was considered necessary for this presentation. In som[illegible]es it will be seen that this description varies somewhat from that above where the present authors feel that additional capabilities should be included such as in the navigation area. Here it is felt that the capabilities of automatic dead reckoning and of computer reduced OMEGA and TRANSIT data should be utilized to develop a completely automatic navigation system.

The purpose of the Integrated Bridge is to provide a work station for the Bridge Watch Team, including facilities for ship control, navigation, maneuvering, internal and external communications, monitoring of the status of the ship's internal safety, record keeping, administration, and other aspects of the Bridge Watch function.

## GENERAL DESIGN PHILOSOPHY

The principal design objective used here was to achieve bridge personnel reduction and an overall improvement in the efficiency and effectiveness of destroyer operations without sacrificing ship's safety (considered in terms of collision avoidance and safe navigation.)

Another design objective was to minimize the cost of procuring the Integrated Bridge System (IBS) and installing it on a DE 1052 class destroyer. The basic consideration in this respect was to ensure that the system included all necessary capabilities while at the same time excluding non-essential ones.

## THE VISIBILITY PROBLEM

An observer standing anywhere on the DE 1052 Bridge, or for that matter on the bridge of almost any ship, has a limited arc of visibility because his field of view is obstructed by the ship's superstructure. Of particular concern is the fact that visibility aft is obstructed--an observer standing at the centerline gyro repeater in the pilothouse, generally conceded to be the best single vantage point for conning the ship--cannot see more than about 45° aft of either beam. To view the ship's quarters or stern area, the observer must move to a bridge wing. Because of this limited visibility, good conning practice dictates that prior to turning the ship, the conning officer should position himself on the bridge wing corresponding to the direction in which the ship will turn.

The Integrated Bridge System (IBS) does not abrogate the necessity for following this conning practice; nor does it in any way restrict its employment. This latter point is particularly important. While the ship is maneuvering in company with other ships, the likelihood is that the Officer of the Deck (OOD)/ Conning Officer will spend little more time operating the Integrated Bridge Console than he now spends operating the radar repeater, working maneuvering board problems, conducting voice radio communications, and checking the contact status board. Exactly how much of the OOD's time is consumed by his direct physical involvement in these activities is not known precisely but it surely cannot amount to more than a few minutes an hour, during even the busiest watches. No doubt the OOD will spend more than this minimal amount of time at the console--but how much more and under what circumstances will not be known until the system has been taken to sea and been thoroughly tested. The one time when the console will most certainly be manned continuously will be when the ship is transiting/piloting in restricted waters. However, in this case, it is more likely that the console operator will be the Navigator, rather than the OOD or the Conning Officer.

## INTEGRATED BRIDGE DUTIES AND RESPONSIBILITIES

The functional duties and responsibilities of the Integrated bridge, considered as an entity, will be essentially the same as the duties and responsibilities of the conventional bridge, similarly considered.

## Proposed Manning

The proposed Integrated Bridge Console is designed for two-man operation. It can be operated by one man and is designed to permit over-the-shoulder viewing of its displays by observers standing behind the console operators.

The duties of the two console operators are described briefly below. These duties are expected to remain fairly constant regardless of the ship's employment. A third person will normally be assigned during regular underway watches to assist the two console operators primarily in the area of ship's administration. However, the design of the Integrated Bridge is compatible with a variety of manning schemes--including one-man operation during periods of limited activity such as independent transits. The team may be comprised of two officers and one enlisted man, one officer and two enlisted men, several officers and enlisted men during special evolutions, as well as other combinations. In short, the IBS has been designed for compatibility with destroyer operations--how the system is manned and operated will depend to a large extent on the desires of individual commanding officers.

During normal at-sea operations, the console will be operated by two men--the OOD and a Ship Controlman, either or both of whom may be seated or standing at the console or free to move about the bridge.

## Duties of the OOD

The Watch Officer's Guide lists 17 specific duties of the

OOD. Of these, the first three, listed below, summarize the OOD's most important duties.

The OOD shall:

1. Keep himself continually informed concerning the tactical situation and geographic factors which may affect the safe navigation of the ship and take appropriate action to avoid the danger of grounding or collision in accordance with tactical doctrine, the rules of the nautical road, and the orders of the commanding officer or other proper authority.

2. Keep himself informed concerning current operation plans and orders, intentions of the OTC and the commanding officer, and such other matters as may pertain to ship or force operations.

3. Issue necessary orders to the wheel and main engine control to avoid danger; to take or keep an assigned station; or to change the course and speed of the ship in accordance with orders of proper authority.

The OOD will operate the left-hand half of the IBS console--the Navigation and Maneuvering Console and the Tactical Information and Communications Console. The Navigation and Maneuvering Console includes the following: (1) an automatic collision avoidance system which detects and tracks contacts and computes their course, speed, and closest point of approach; (2) a system for solving maneuvering problems; and (3) an automatic navigation system. (The Integrated Bridge will

include automatic OMEGA and TRANSIT satellite systems for use in open ocean navigation.) The Tactical Information and Communications Console provides facilities for (1) both internal and external communications and (2) a display of tactical information sufficient to enable the OOD to monitor weapons firing safety.

Duties of the Ship Controlman

The right half of the console is equipped with steering and propulsion controls, a ship's lights control panel, and communications facilities. This portion of the console will normally be operated by the Ship Controlman. The Ship Controlman will act as an assistant to the OOD. That is, he will not only operate the steering and propulsion controls, but will assist the OOD in such areas as internal and external communications, administration, and navigation.

## INTEGRATED BRIDGE LAYOUT

Figure 22 is a plan view of the proposed layout for the Integrated Bridge. The console will be located adjacent to the forward bulkhead of the pilothouse. The Ship Controlman's station will be located on the ship's centerline, i.e., the console will be offset 15" to port.

A conventional chart table will be located aft of the console. Sufficient space will be provided between the console and the chart table to provide a walkway for athwartship's foot traffic.

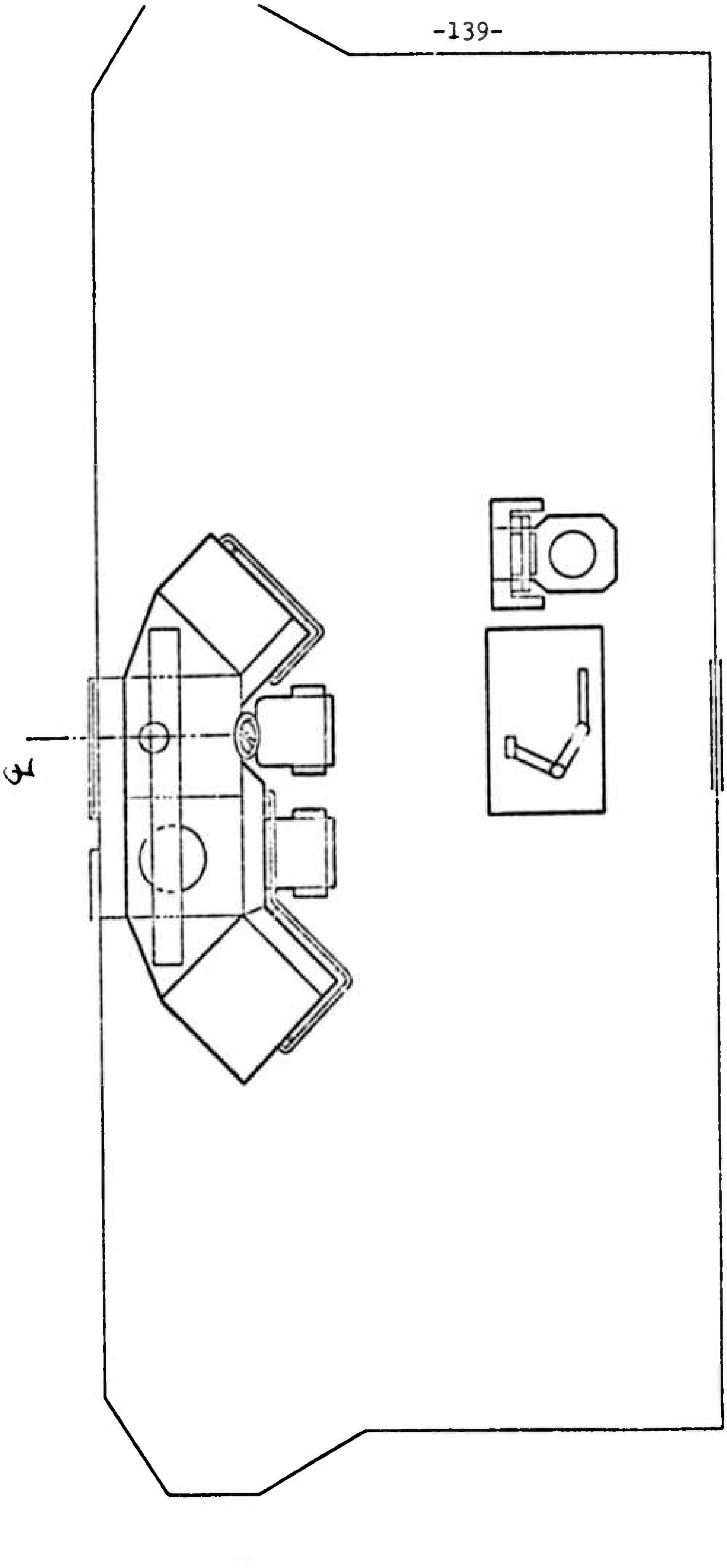


FIGURE 22

INTEGRATED BRIDGE LAYOUT

A standard AN/SPA-25 radar repeater will be located immediately to the right of the chart table. An OMEGA (automatic electronic navigation system) display will be mounted from the overhead directly above the radar repeater.

In addition to the main console, the Integrated Bridge System includes a fiddleboard display and a movable pelorus. Both operators will be able to read, while seated, all of the information displayed on the fiddleboard and to use the moveable pelorus. Four high visibility displays are also located on the fiddleboard (ship's course and speed, ships position, time, and water depth). These displays will be readable from anywhere on the Bridge.

## FUNCTIONAL CHARACTERISTICS OF THE INTEGRATED BRIDGE SYSTEM

The following sections present a detailed description of the functional characteristics of the IBS console.

### Console Configuration

Figure 23 is a plan view of the console showing its eight major parts.:

1. Tactical Information and Communications Panel (TAC INFO & COMM)

2. Navigation and Maneuvering Console Auxiliary Panel (N&MC AUX)

3. Navigation and Maneuvering Console (N&MC)

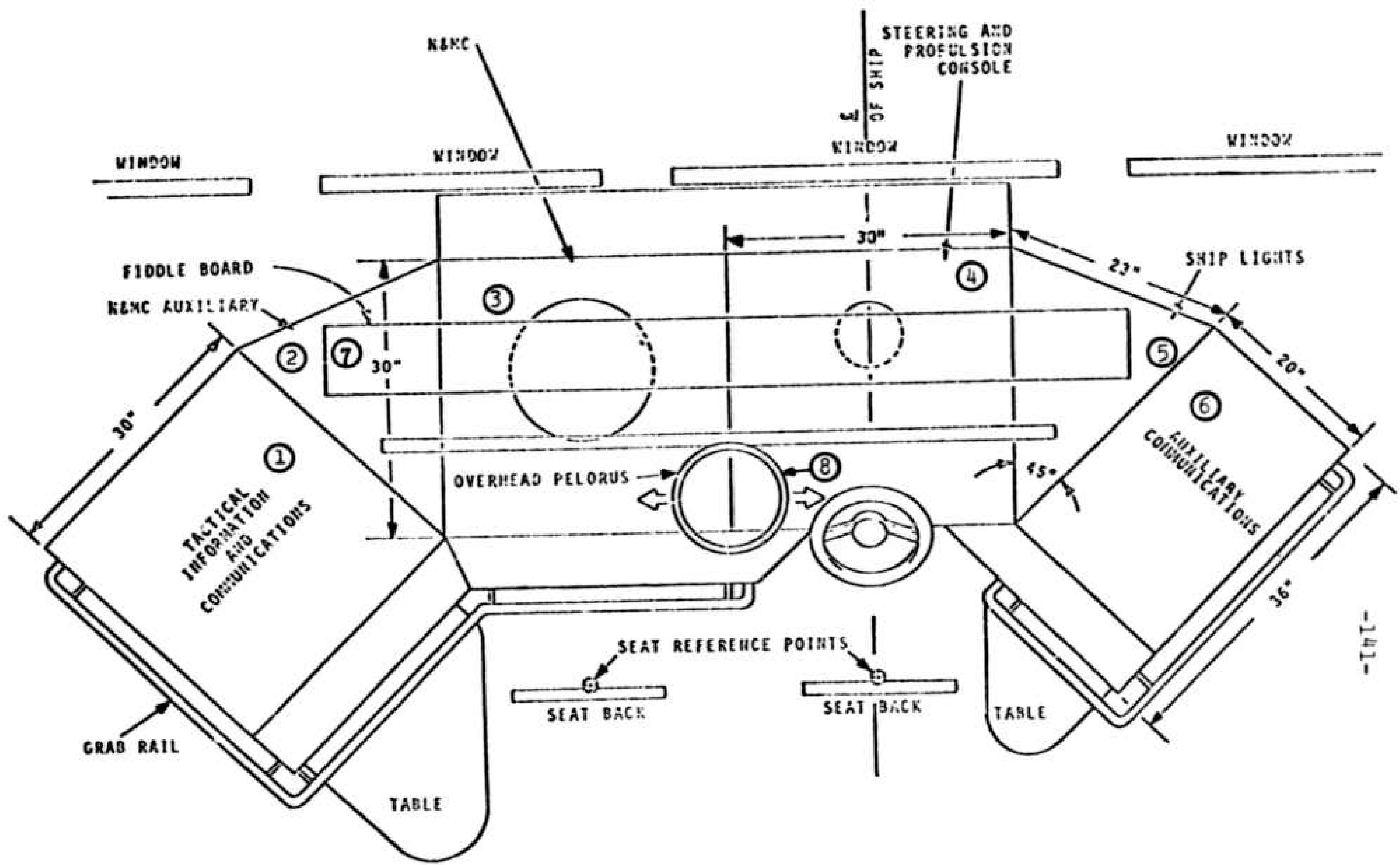



FIGURE 23

INTEGRATED BRIDGE CONSOLE DIMENSIONS

4. Steering and Propulsion Control Console (STR & PROP).

5. Ship's Lights Control Panel (SHIP LITES).

6. Auxiliary Communications Panel (AUX COMM).

7. Fiddle board.

8. Overhead pelorus.

The size of the console is approximately twelve feet in width and six feet in its fore and aft depth. The purpose of the 45° angle between the two end panels and the center of the console is to ensure that all controls will be within the reach envelope of one or the other of the two operators.

Figure 24 shows a cross-sectional view of the Navigation and Maneuvering Console. An outline of a 5th percentile man is also shown in the figure. The double exposure of the man's legs is intended to demonstrate that his torso and eye positions can remain unchanged whether he is seated or standing. This effect can be achieved for any operator simply by lowering or raising the height of his chair to match his standing leg height.

The Integrated Bridge will include an overhead pelorus. This device is being proposed as a replacement for the DE 1052's centerline gyro repeater which will be removed to make room for the Integrated Bridge Console. The pelorus will slide athwartships on a 9' metal rod and, except when in use, it will be stowed at one end or the other of the slide rod. In Figure 24, the pelorus is shown in its in-use position to demonstrate

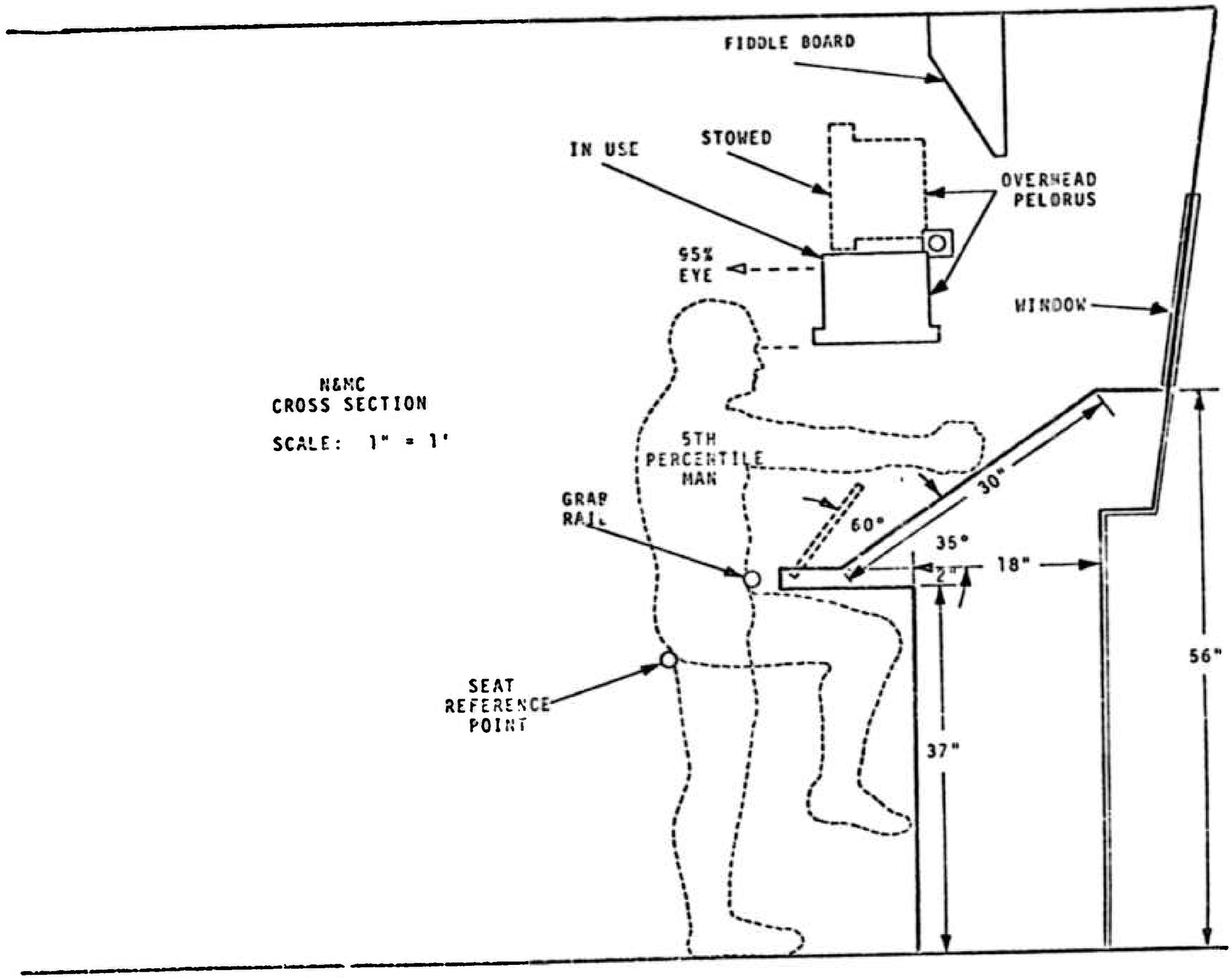



FIGURE 24

INTEGRATED BRIDGE CONSOLE SIDE VIEW

that its lower surface, on which a sighting device will be mounted, is in line with the 5th percentile man height of eye.

In the drawing, just above the man's head, there appears a black triangle representing the height of eye for a 95th percentile man. Notice that when it is in its stowed position the overhead pelorus is above the 95th percentile man height of eye.

The knee space provided under the console is sufficient to accommodate a 95th percentile man seated with his abdomen resting against the grab rail. Additional knee space can be made available by moving the adjustable chair farther aft. Therefore, it is expected that there will be ample knee room for all operators.

The height and slope angle of the console's control and display surface is designed to facilitate operation of its controls and to minimize parallax distortion in the reading of its displays for both large and small operators whether seated or standing.

The forward side of the console is designed to conform to the configuration of the forward bulkhead of the DE 1052's pilothouse--hence its somewhat peculiar shape.

## The Navigation and Maneuvering Console (N&MC)

The N&MC will serve three primary functions: collision avoidance, navigation, and ship maneuvering. The N&MC is an interactive computer graphics system, consisting of a computer, a main and an auxiliary display, operator control devices, and a radar interface device.

Figures 25 and 26 are scale drawings of the proposed Navigation and Maneuvering Console (N&MC) and the Navigation and Maneuvering Console Auxiliary Panel (AUX Panel), respectively.

The N&MC features two CRT displays, the Main Display, and the Auxiliary Display.

The Main Display will be a computer graphics terminal. It will be used for displaying symbolic representations of own ship and its immediate surroundings superimposed upon a processed (scan-converted) radar background. Its useful display surface will measure not less than 16" in diameter.

The Auxiliary Display will be a CRT or other type display suitable for displaying alphanumeric information. It will be used for displaying the solutions to the problems solved by the N&MC and for presenting amplifying information of various types such as buoy lists, contact data, etc.

In Figure 25, the Auxiliary Display is shown as a 7" x 12" rectangle. This represents a maximum permissible size. The actual size of the Auxiliary Panel is expected to be smaller than this and will be determined by the content and format of the information to be displayed.

The N&MC also includes four dedicated readouts that will be implemented using light emitting diodes (LED's). These readouts include (clock) time, elapsed time, indicated course and speed, and a display of the bearing and range to a designated point. Time and elapsed time are self-explanatory. Indicated

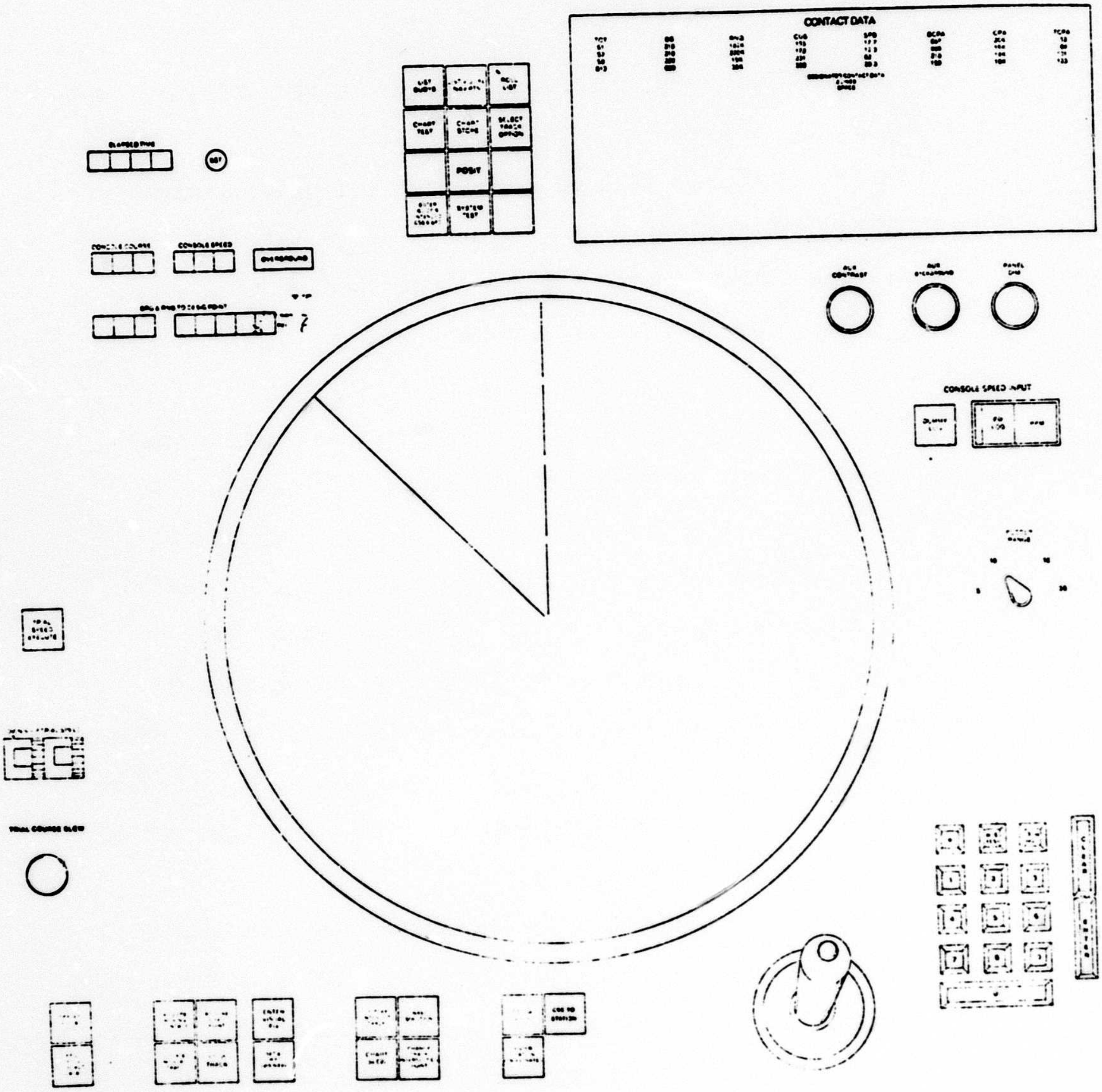



FIGURE 25

NAVIGATION AND MANEUVERING CONSOLE

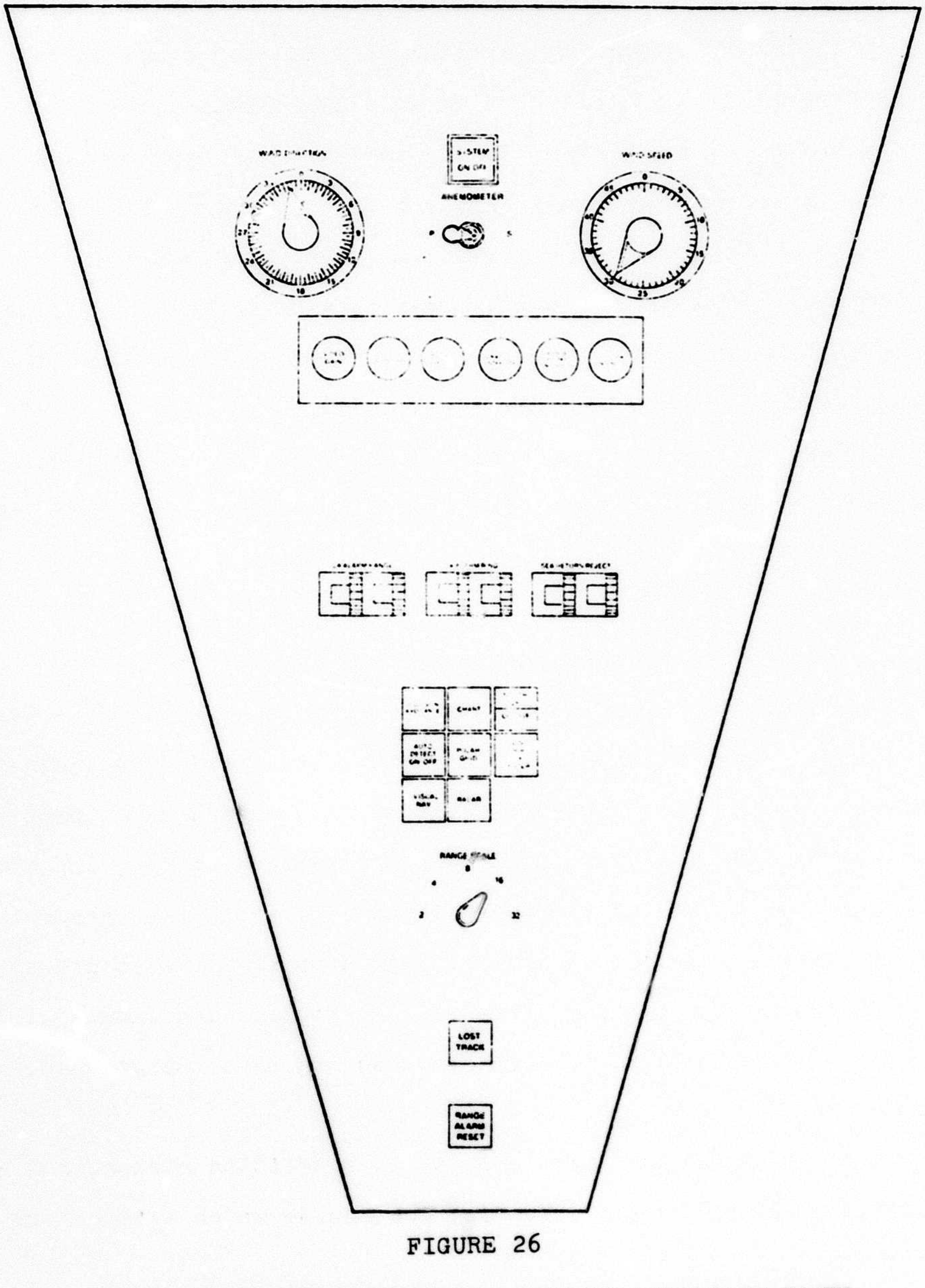



FIGURE 26

NAVIGATION AND MANEUVERING CONSOLE AUXILIARY PANEL

course and speed may either represent input values, i.e., gyro course and shaft RPM, or EM Log speed; or they may represent computed values of the ship's actual course and speed made good over the ground. When the console is utilizing computed values, the "overground" indicator light will be illuminated.

The bearing and range to designated point readout will normally display the range from own ship to the position indicated by the position designation symbol (not shown in the drawing). This readout will, however, also be used to display the bearing and range between any two desired points when the appropriate function button is selected.

Several operator controls are also located on the N&MC. Their functions, and tentative nomenclature, are listed in Table V.

<u>Collision Avoidance System (CAS)</u>

The CAS is intended to provide the OOD with a decision-aiding tool to assist him in avoiding collisions with other ships.

The system detects and tracks contacts within the vicinity of own ship and computes their course, speed, and closest point of approach (CPA), including CPA bearing, range, and time. It includes a warning system designed to alert bridge personnel to potentially dangerous approach situations. It also presents the OOD with easily interpretable, unambiguous decision action choices to aid him in selecting course or speed changes necessary to avoid collision.

It is emphasized that the CAS is a decision aiding, not a decision making device. It does not decide which actions are

TABLE V

NAVIGATION AND MANEUVERING CONSOLE CONTROLS

DESIGNATION FUNCTIONS

| | Nomenclature | Function | Associated Display |
|---|---|---|---|
| 1. | Slewing Device (Joystick) | Slew position/contact designation symbol or chart or grid. | Main |
| 2. | Offset Bearing and Range | Enables bearing and range measurements between any two points. When depressed a second time, disables function. | Main and Dedicated |
| 3. | Acquire Moving Contact | Initiates track on contact when designation symbol is positioned over contact and the automatic detection function is turned off. | Main |
| 4. | Acquire Fixed Target | Initiates track on fixed target when designation symbol is positioned over a radar chart registration or lock point. When lock point is tracked, console is driven by auto track output. | Main |
| 5. | Request Designated Contact Data | Initiates data dump of contact's course speed and CPA information on contact indicated designation symbol. | Auxiliary and Main |
| 6. | Stop Track | Discontinues track on a contact, fixed or moving. | Auxiliary and Main |

TABLE V (Cont.)

| Nomenclature | Function | Associated Display |
|---|---|---|
| 7. Enter Visual Fix | Causes a symbol to be displayed at the point designated by the acquisition symbol. | Main |
| 8. Update Manual Track | Designates and updates targets during manual track function. | Main |
| 9. Chart Slew | Enables the chart slewing function. Slewing is controlled by moving the joystick. | Main |
| SPECIAL FEATURES | | |
| 1. Trial Speed Execute | Momentary switch that enters a fictitious speed into the system for test purposes. | Auxiliary and Main |
| 2. Display Intended Track | Causes an intended track to be displayed on the main display. | Main |
| 3. Chart Test | Causes computerized navigation chart to be displayed on the main display regardless of own-ship's present position. | Main |
| 4. Elapsed Time Button | Start/stop/reset elapsed time clock. | Dedicated |
| 5. Replay | Allows operator to replay up to four hours of console activity that has been stored on the system's automatic recorder. | Auxiliary and Main |
| 6. Alarm Acknowledge | Resets audible alarm. | |
| COMPUTATIONS | | |
| 1. Designate Guide | Identifies a contact as the formation guide. | Auxiliary and Main |

TABLE V (Cont.)

| | Nomenclature | Function | Associated Display |
|---|---|---|---|
| 2. | Enter Station Coordinates | Enables entry of station coordinates function (true bearing and range to the guide). | Auxiliary and Main |
| 3. | Course to Station Solution | Enables course to station routine and causes solution to be displayed. | Auxiliary and Main |
| 4. | Enter Guides Intended CSE & SPD | Enables course to station problem routine with change of guide course and speed. | Auxiliary |
| 5. | List Buoys | Causes amplifying buoy data to be displayed in roll chart format. | Auxiliary |
| 6. | List Visual Nav Points | Causes amplifying data on visual navigation points to be displayed in a roll chart format. | Auxiliary |
| 7. | Auxiliary Display Roll | Controls auxiliary display page roll feature. This feature permits the operator to view all of the contact or navigation amplifying information presently stowed in the computer. | Auxiliary |
| 8. | Data Entry | Enters data selected on numerical keyboard. | Auxiliary |
| 9. | Clear | Removes data and allows correction of entered data. | Auxiliary |
| 10. | POSIT | Causes Lat/Long to be displayed and provides a means of updating DR. | Auxiliary |
| 11. | Numerical Keyboard | Provides for number entry (0-9, + or -, N/S, E/W, and decimal point). | Auxiliary |
| 12. | Select Track Options | Displays and enables selection of intended tracks. | Auxiliary and Main |

TABLE V (Cont.)

| | Nomenclature | Function | Associated Display |
|---|---|---|---|
| 13. | Change Intended Track | Enables intended track change function. | Auxiliary and Main |
| 14. | Nav Solution | Enables piloting problem solution (i.e., time to turn, distance to turn, and course to steer). | Auxiliary and Main |
| 15. | Set and Drift | Enables set and drift computation function (based on visual fixes). | Auxiliary |
| 16. | Chart Store | Enables operator to enter specific chart. | Auxiliary |
| INPUT CONTROLS | | | |
| 1. | Trial Speed (Thumb wheel) | Allows operator to insert a trial speed for collision avoidance and computations. | |
| 2. | CPA (Thumb wheel) | CPA distance set for alarm criteria. | |
| 3. | Range Ring Alarm Set (Thumb wheel) | Range set for alarm criteria. | |
| 4. | Rudder Angle (Four Position Selection Switch) | A means to enter rudder angle for turn computations. | |

to be taken nor does it have any sort of automatic output device for directly controlling or altering own-ship's course or speed.

The CAS will have three modes of operation: automatic detection and tracking, manual detection and automatic tracking, and manual detection and tracking. In each of these modes, the system is designed to track up to 40 contacts. In the automatic detection mode, the system selects and tracks the 40 most threatening contacts. Contact threat is based on CPA range and time to CPA. Thus, when there are more than 40 contacts within radar range, the system will keep track of the 40 contacts that will approach own ship most closely and in the shortest period of time. The system will be designed to compute all contact parameters--course, speed, CPA, etc., within two minutes after detection.

To be accepted as contacts by the system, radar targets must meet the following criteria: they must be less than 1500 feet in length, i.e., the system will not track large land masses;* and the relative speed between own ship and the contact must be less than a preset value. In the prototype system, a control will be provided to vary this value between 70 and 100 knots.

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* The system is, however, capable of tracking land masses that will present a small radar cross section. This topic is addressed in the section describing the N&MC's navigation capabilities.

Collision Avoidance Display Formats

Two types of display formats are used: computer graphics and a tabular alphanumeric display.

Figure 27 is a conceptual drawing of a closest point of approach contour (CPAC). The CPAC is a circle whose radius is equivalent to the CPA range alarm criterion selected by the console operator. Actually, the CPAC may be either circular or elliptical, depending upon the geometric relationship and relative motion between own ship and the contact. We will limit our discussion to circular CPAC's. The CPAC is centered on the end of the contact's course vector. The course vector originates from the location of the contact's radar return--no contact symbol per se is displayed.

The end of the contact's course line represents the point at which own ship would collide with the contact if (1) the contact maintained course and speed, and (2) own ship maintained present speed and steered the course to intercept the contact, i.e., the course represented by the azimuth connecting ownship's present position with the end of the contact's course vector.

The CAS is a real-time system. It receives a new data input every sweep of the ship's radar. Between radar sweeps, the system, in effect, dead reckons its presentation. Thus, as the relationship between own ship and the contact changes, the CAS display updates. For example, the length of the contact's course line may initially be 8000 yards. If own ship were to close the contact, thereby reducing the instantaneous time required

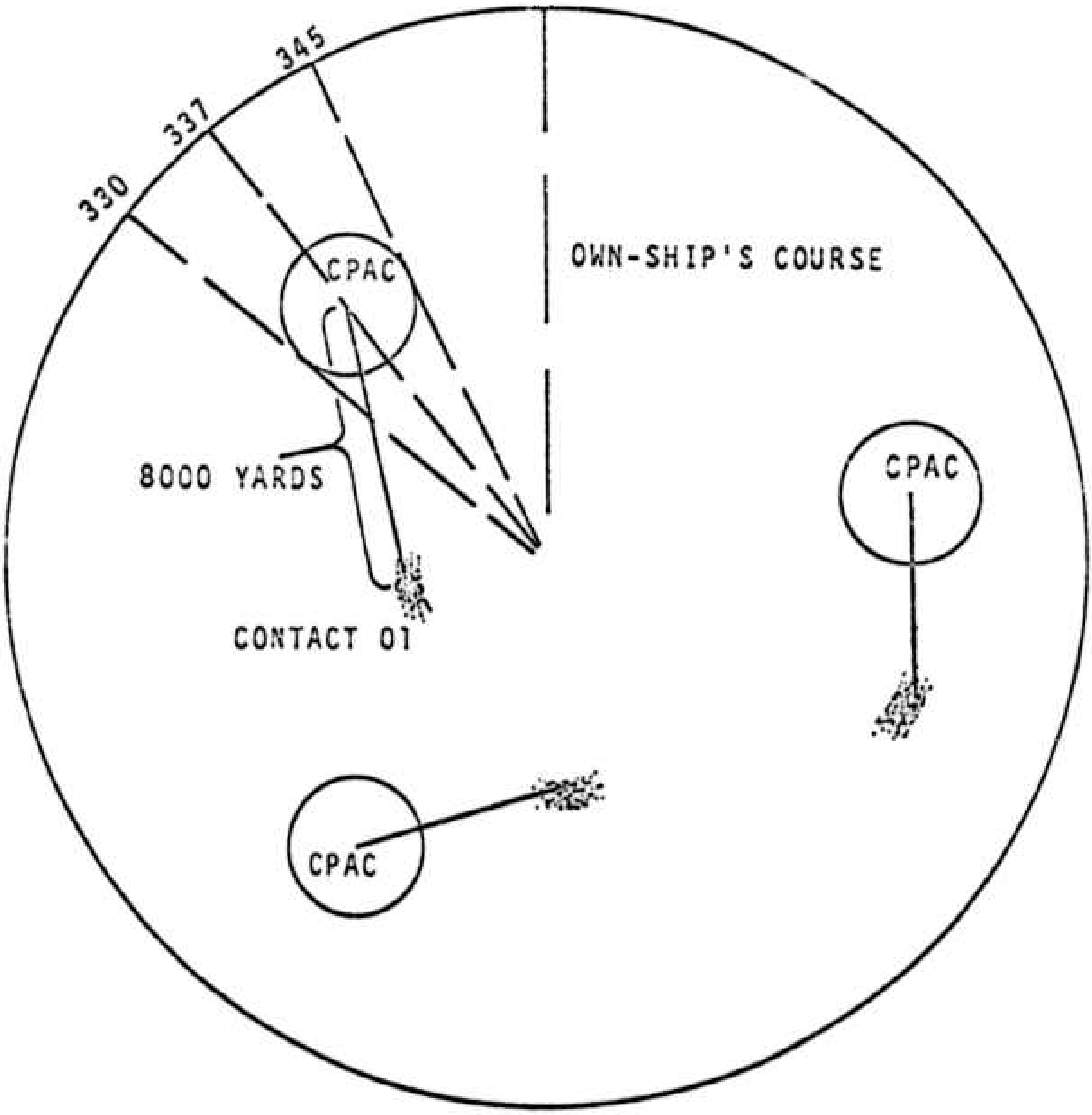


FIGURE 27

CPA CONTOURS

to intercept, the contact's course line would become progressively shorter. If Contact 01 were to accelerate, its course line would increase in length because even if the intercept time remained unchanged, which obviously it would not, 01 would still travel farther in the time required to intercept. The converse is also true. If 01 slows,its course line will decrease in length. Changes in own-ship's speed will, in our example, have the opposite effect of changes in 01's speed. That is, if own ship accelerates, the length of 01's course line will decrease because the relative speed will have been increased thus reducing the time required to intercept, thereby reducing the distance 01 would travel during the intercept. A reduction in own-ship's speed would produce an increase in 01's course line.

The CAS will automatically evaluate the threat posed by each contact (based on time to CPA and CPA range). Contact data for the five most threatening contacts will be continuously displayed, in a tabular format, on the Auxiliary Display. The displayed information will consist of an identification number, present bearing and range, contact present course and speed, bearing and range of CPA and time to-go-to CPA, and clock time of CPA. In addition, the system will include a function that will enable the operator to obtain a continuous display of contact data for two additional contacts of his choice.

A contact data page function will also be included in the system. When actuated, this function will cause a complete list of all active contacts to be presented on the Auxiliary Display.

Computer Aided Navigation System (CAN)

The Computer Aided Navigation System represents perhaps the most innovative single feature of the entire Integrated Bridge System, It is intended to replace present navigation and piloting procedures. The CAN will consist of a computer, OMEGA and TRANSIT satellite receivers, a series of magnetic tape cassettes containing reprsentations of harbor charts, the N&MC main and auxiliary displays, and operator controls for interacting with the system.

The piloting phase of the CAN will have two modes of operation: an automatic radar mode and a semiautomatic visual mode. The radar mode will be the primary mode and will be used in harbors where satisfactory radar targets are available. The visual mode is a backup mode and will be used in harbors not having satisfactory radar targets. Provision is also made for simultaneous operation of the radar and visual modes. (As an additional backup, a standard chart desk will be retained on the Integrated Bridge for use in the event of a failure to the automatic system.)

Figure 28 is a representation of some of the CAN chart features. The following items, not all of which are shown in Figure 28, are to be included in the software generated chart:

1. Coastline (straight line approximations of prominent coastal features suitable for radar/chart matching).

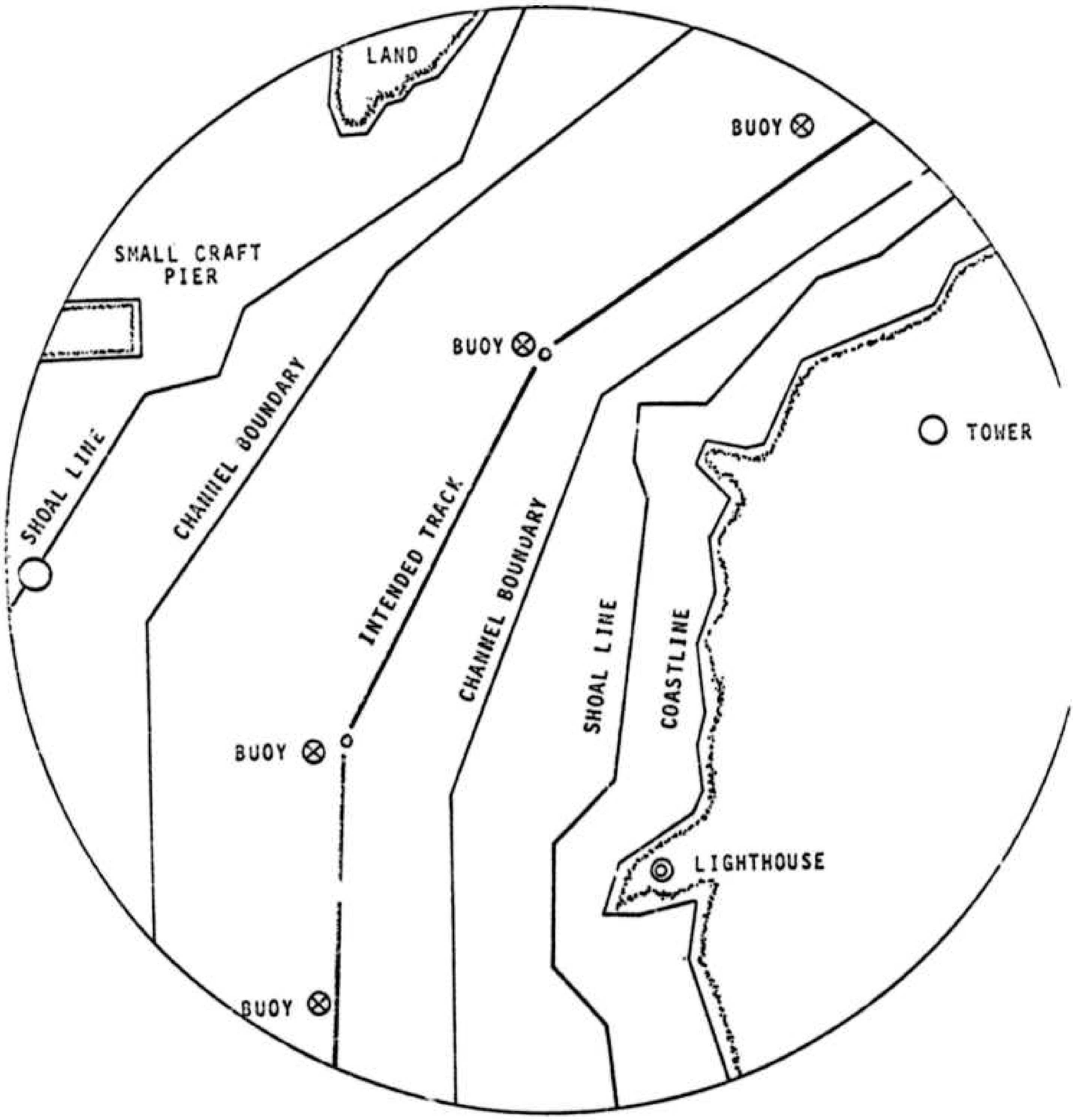


FIGURE 28

COMPUTERIZED HARBOR CHART (INTENDED TRACK)

2. A shoal line corresponding to the draft of the ship (straight line approximation biased towards deep water).

3. Channel outline.

4. Intended track lines.

5. Hazards to navigation (within the navigable water).

6. Danger bearings.

7. Prominent radar navigation points such as lighthouses and other fixed (discrete) radar targets.

8. Visual sighting points (stacks, tanks, towers, cupolas, etc.)

9. All usable aids to navigation (buoys, lighthouses, range lights, towers, etc.).

10. Lat/Long reference point (not displayed).

11. Such other items as are required for navigation safety and clarity of the chart presentation.

Navigation and Maneuvering Console Display Recorder

The N&MC will be equipped with a recorder capable of providing a four-hour reconstruction of console activity. The following values will be recorded:

1. Time.

2. Ship's course.

3. Ship's speed.

4. Collision avoidance system inputs.

5. Computer generated chart.

6. Visual fix bearings.

The system will not record raw radar video. Reconstruction will be accomplished by playback of the recorded tape through the N&MC. During playback, all symbolic and alphanumeric information normally presented on the main, auxiliary, and dedicated displays will be presented. This information will be sufficient to show own-ship's relationship to other ships and to land masses.

<u>Tactical Information and Communications Console</u>

The purpose of the communications system design is to consolidate at a central location all of the communications facilities required for effective internal and external communications. This concept is implemented using existing internal and external subsystems except that the operator interface equipment is reconfigured. (see Figure 29).

<u>External Communications Systems</u>

The external communications facilities to be included in the Integrated Bridge Console are shown in Figures 29 and 30.

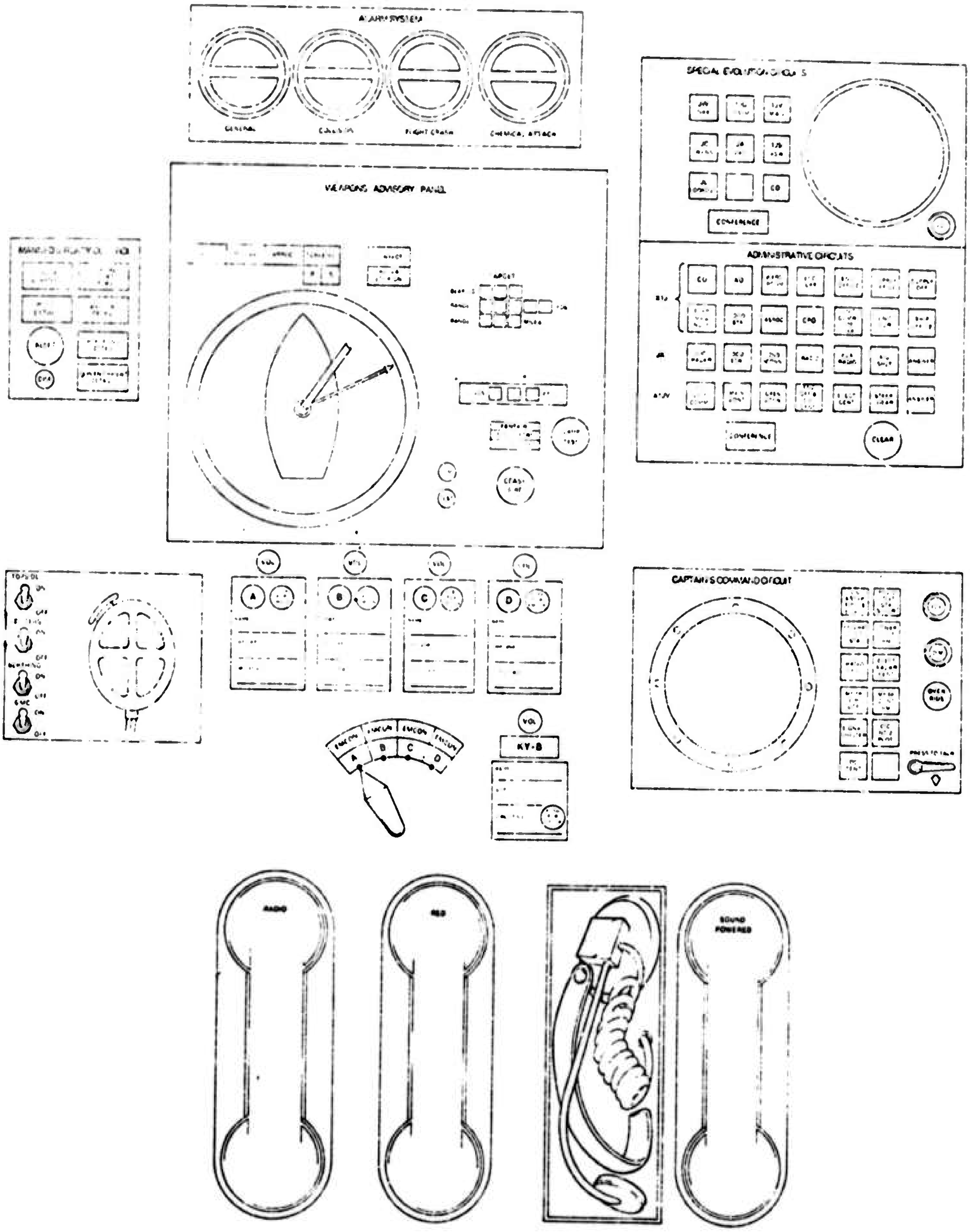


FIGURE 29

TACTICAL INFORMATION AND COMMUNICATIONS CONSOLE

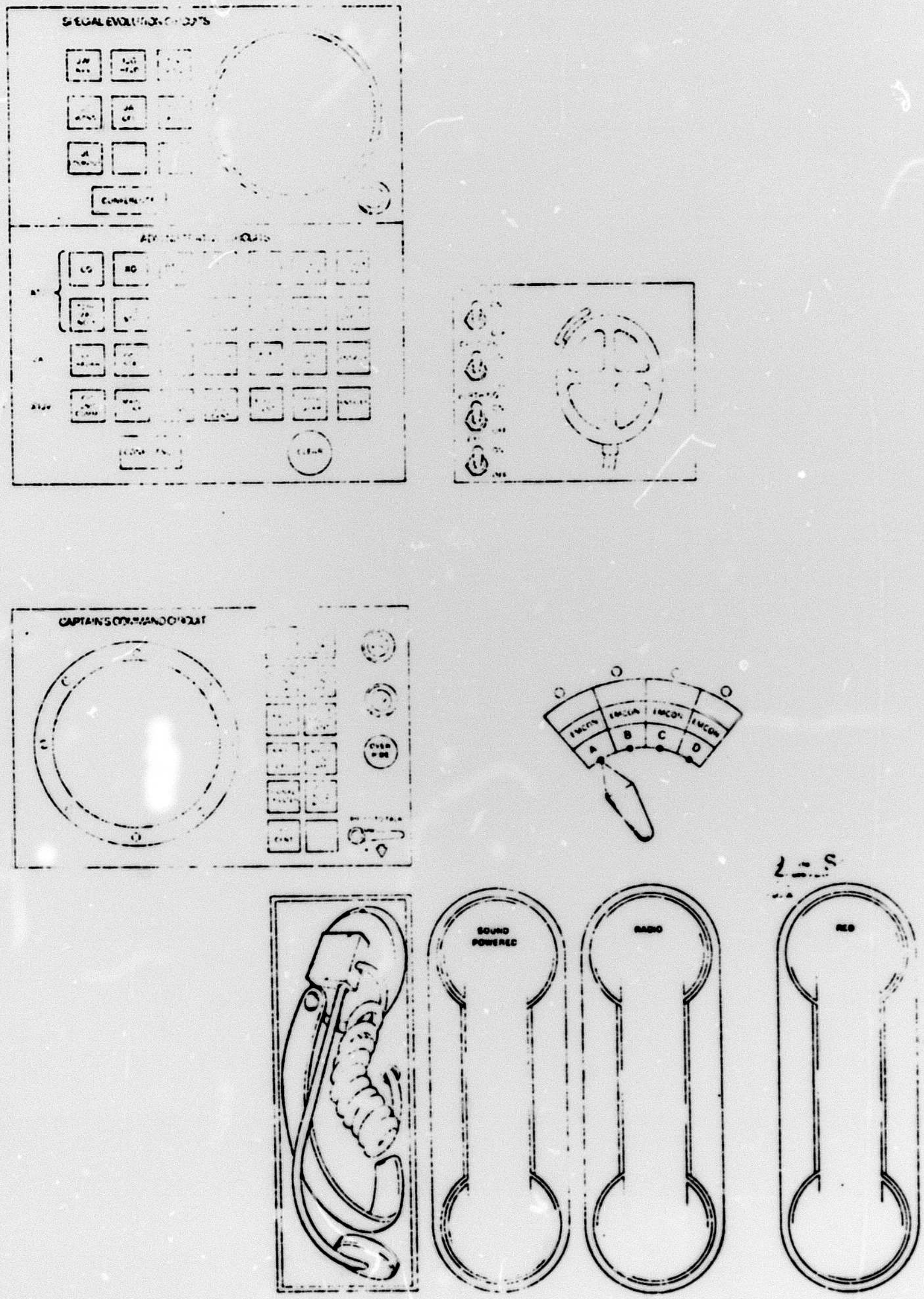


FIGURE 30

AUXILIARY COMMUNICATIONS PANEL

Two radio telephone handsets will be provided on the Tactical Information and Communications Panel. One of these will be a red handset which will be dedicated to the secure (covered) voice radio system (KY-8). The other handset will be black. It will be associated with a rotary selector switch having positions labeled A, B, C, and D. The selector switch will connect the black handset to any of the four circuits indicated by plastic identification cards to be located just above the selector switch.

Steering and Propulsion Control Console (Figure 31)

The steering system for the Integrated Bridge does, to some extent, reflect the characteristics of available (off-the-shelf) steering systems that have been accepted for service use. Though perhaps less than ideal, these characteristics are, in general, considered satisfactory.

Steering System Functional Description

The steering control system will include three modes of operation: hand-electric or manual, auto-pilot, and an emergency or non-followup mode. The system will include three steering order input devices: a steering wheel to be used in the manual mode, a handcrank to be used in the auto-pilot mode, and a lever-type control for the emergency or non-follow-up mode. A three-position mode selector switch will be provided for selecting the EMERgency, HAND, or AUTO mode of operation. In addition, the system will include a two-position selector switch for selecting

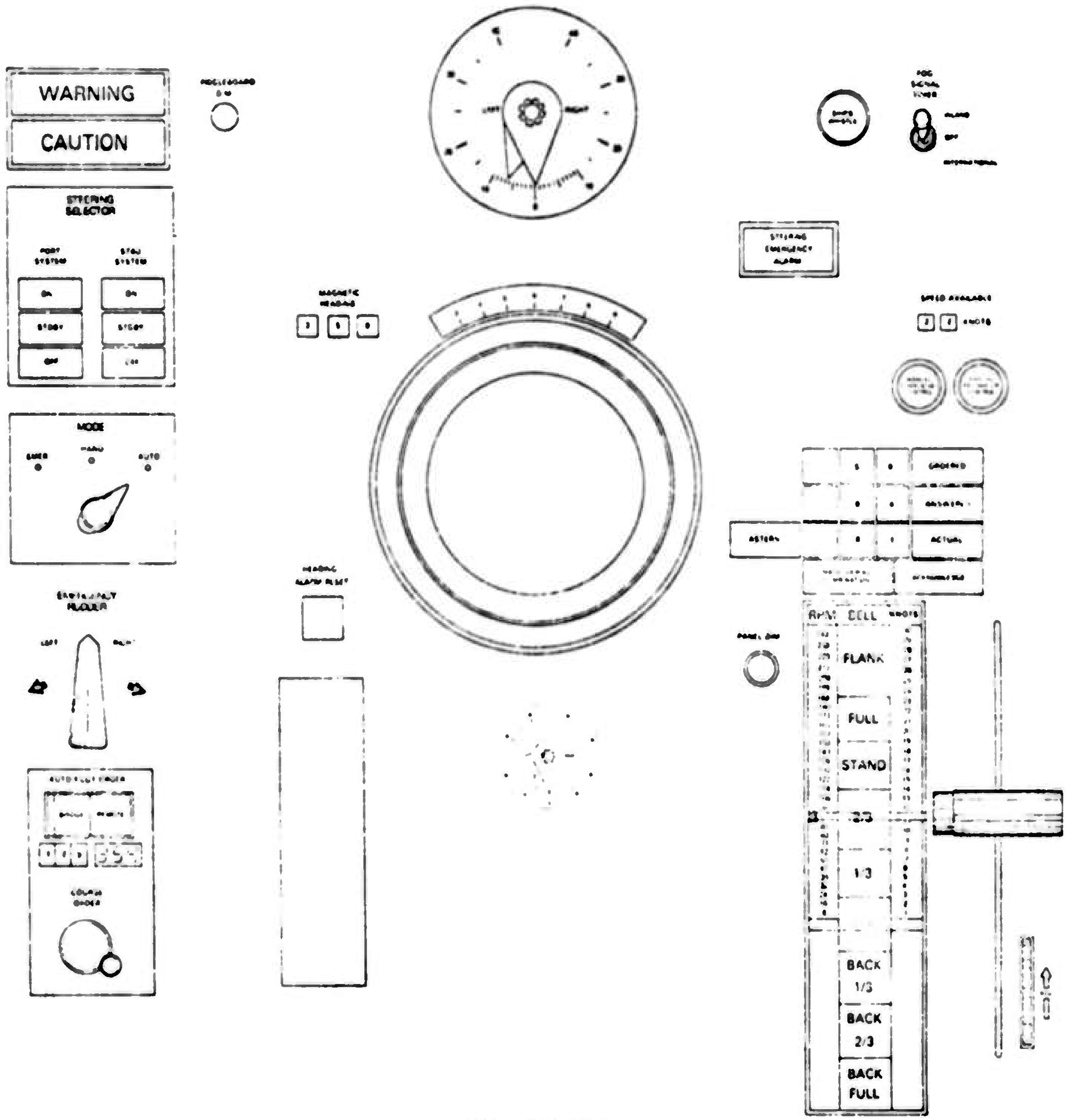


FIGURE 31

STEERING AND PROPULSION CONTROL CONSOLE

the source of the auto-pilot course order input. This switch shall be labeled BRIDGE and REMOTE.

A port and starboard steering system control panel will be located just above the mode selector switch. This panel will include ON and OFF push button switches for both the port and starboard steering systems (four separate switches) plus port and starboard system in STANDBY indicator lights (two separate indicators).

Auto-Pilot Adjustment Controls

These controls will be used to establish auto-pilot rudder response parameters. They will be located in a covered enclosure on the Steering and Propulsion Control Console.

1. Rudder Limit Control. This control will limit the number of degrees of rudder which the auto-pilot can order in response to a steering signal error, whether this error is a result of coursekeeping fluctuations or the result of an ordered course change. This limit will be continuously adjustable from 2° to 35° of rudder response.

2. Rudder Ratio Control. This control will establish the ratio between heading error, in degrees, and rudder response, also in degrees. This ratio shall be continuously adjustable from 1 to 3.

3. Weather Adjustment. This control is to be used to establish the sensitivity of the auto-pilot in responding to heading errors. Typically, as sea state increases, ship's yaw also increases. The weather adjustment will be used to control, usually to reduce rudder response due to weather induced yaw. This control will be continuously adjustable from 0° to 5°.

4. Heading Alarm Set. This control will be used to set the permissible number of degrees of heading error required to establish a heading error alarm condition. It will be graduated in single-degree increments from 1° to 10°.

5. Heading Alarm Reset Push Button. This push button will be used to silence the heading error alarm. It will be located adjacent to the covered enclosure containing the Auto-Pilot Adjustment Controls.

System Displays and Indicators

1. Ship's Course Indicator. This display will be located in the approximate center of the Steering and Propulsion Control Console. It will be a gyro repeater with a fully visible 360° compass card driven by the ship's master gyro compass. The compass card shall be marked off in single-degree increments and

labeled every 10 degrees, 0° - 350°. A lubber's line will be provided to indicate ship's course.

2. Ship's Course Vernier Display. This display will be located just above the ship's course indicator. It shall display 5° of heading in one half-degree increments centered on present ship's course. It shall also have a lubber's line.

3. Digital Readout of Magnetic Heading. The existing magnetic compass stand (binnacle) will be removed from the Bridge. It will be replaced by a highly reliable magnetic flux gate, or similar device, from which an output can be obtained to provide a digital readout of ship's magnetic heading.

4. Ordered Ship's Course Displays. Two ordered course digital displays, both associated with the auto-pilot will be provided. They will be located just above the auto-pilot course order handcrank. One display will be a mechanically driven counter. The other will be an electronic (LED) display. The inputs to these displays is discussed in the section on System Operation.

5. Rudder Angle Displays. Three types of information related to rudder angle will be displayed--rudder or helm order, actual rudder position, and in the special case of emergency (non-follow-up) operation, the

rudder output of the steering system actuator.

The rudder order indicator and the actual rudder position indicator will be combined into a single dial-type display mounted just above the ship's course indicator. One pointer on this dial will indicate rudder order; the other pointer will indicate actual rudder position. The scale on the dial face shall be calibrated from 40° right to 40° left rudder. Scale marking shall be provided for each degree from 0° to 10° and for each five degrees from 10° to 40°. The dial shall be labeled every 10 degrees with 0 at the bottom of the dial and 10, 20, 30 and 40--to the left and right of center. The spacing of the dial markings will be in accordance with those shown in Figure 31.

A second dial-type rudder order display will be provided for displaying emergency rudder (non-follow-up) orders. This display will also have two pointers but, in this case, one pointer will be used to indicate starboard steering system rudder orders, and the other will be used to indicate port system rudder orders. This display will have one-half the diameter of the previously described rudder display. The markings on the dial face of this display will be identical to those on the indicator described in

the preceding paragraph.

NOTE: Having a separate rudder indicator for the non-follow-up unit is considered to be a less than desirable compromise between what is operationally desired and the steering systems presently known to be available. A more desirable arrangement would be to have one pointer on one dial indicate rudder order regardless of the origin of the order or, if additional pointer(s) are required, to at least incorporate them into the primary rudder order display.

Steering System Operation

The steering will include duplicate (port and starboard) electrical control circuits as well as duplicate (port and starboard) electro-hydraulic power transmission systems. Only one of the two systems will control the rudder at any given time. However, both systems may be turned on at the same time, in which case one system will be controlling the rudder and the other will be in standby.

Each system includes a hydraulic pump and associated accumulators. The first pump turned on is the one that will supply power to the rudder. The other hydraulic pump, if turned on, will idle or operate in a standby condition, unless or until the output pressure of the first pump drops below a

predetermined value. (Actually, until the output pressure of the standby pump exceeds the output pressure of the first pump). With one pump on the line and the other in standby, the changeover from one pump to the other in the event of a failure of the operating pump will be, as is presently the case, all but instantaneous. For all practical purposes, no loss of rudder control should be experienced during the changeover from the first pump to the standby pump.

To avoid unnecessary wear, the second system is not turned on (is not placed in standby) during normal operations. However, the second system is almost always placed in standby during Special Sea Detail evolutions or other close maneuvering situations.

Failure Modes

Any time a system failure occurs, an alarm will be sounded. If both pumps are on--one supplying system power and the other in standby--a LOST STANDBY STEERING caution alarm will sound if either system fails. If the ON pump fails, the alarm will sound and the standby pump will begin supplving system power automatically. If the standby pump fails, the alarm will sound to indicate the loss of the backup system.

If only one system is turned on, and it fails, the LOST STANDBY STEERING caution alarm will sound, and the other system will turn itself on automatically and begin supplying power to the system. If the second pump fails to start, the STEERING POWER FAILURE warning alarm will sound.

Steering Modes

Auto-Pilot

This mode of operation will be established by placing the Mode Selector Switch in the AUTO position. When in this mode of operation, the system will automatically maintain ordered course to within the limits established by the auto-pilot fine adjustment controls. Course orders will originate at the Bridge Console, or from a remote station, depending on the setting of the Auto-pilot Order Selector Switch. When this selector switch is in the BRIDGE position, the auto-pilot course order hand-crank, located on the lower left-hand corner of the Steering and Propulsion Control Console, will be used for entering course changes. Turning this handcrank will drive the mechanical counter (left-hand) ordered course display. The electronic (right-hand) course order display will follow the mechanical counter and also display ordered course. When the auto-pilot order selector is in the REMOTE position, course orders will drive the electronic course order display but the mechanical counter display will not follow. That is, only coincidentally will the mechanical and the electronic course order displays be matched when course orders are originating from a remote station.

When control is shifted from the remote station to the bridge, the ordered course will be the course ordered by the conning station last in command. For example, if present ship's course, as ordered by the remote station prior to relinquishing

control to the bridge, is 180°, then the mechanical display must be equipped with a servo driven device to follow this ordered course when the Auto-Pilot Order Switch is placed in the BRIDGE position.

The Bridge will have a capability of overriding remote course orders by (1) placing the Auto-Pilot Order Switch in the BRIDGE position; (2) de-selecting auto-pilot on the Mode Selector Switch; or (3) taking direct control of the rudder with the Emergency Rudder (non-follow-up) control lever.

Auto-Pilot Heading Error Alarm

The purpose of this alarm is to inform the operator whenever present ship's heading deviates from ordered course by a predetermined value. This value can be varied between one and ten degrees and will be established by setting the Heading Error Alarm. The alarm will be silenced by pressing the Heading Alarm Reset push button. The heading alarm will not be activated by course changes ordered by the bridge. That is, when a new course is ordered, the Heading Error Alarm will be automatically deactivated until the ship has completed its turn and the correspondence between present ship's course and ordered ship's course is less than the value set for the Heading Error Alarm. Once this condition is met, the alarm will reset itself automatically and sound for any subsequent non-ordered deviations meeting its alarm criterion. The Heading Error Alarm will also sound when course changes are ordered from the REMOTE

station provided, of course, that the course change is large enough to exceed the criterion value.

Hand Electric

This mode of operation will be established by placing the Mode Selector Switch in the HAND position. Turning the steering wheel will generate rudder orders which will be displayed on the rudder order indicator and transmitted to the steering gear via the port or starboard steering cable. The rudder position indicator will display the actual present position of the rudder. The maximum amount of rudder than can be ordered using this system will be limited to 35°.

Emergency

This mode of operation will be established either by placing the Mode Selector Switch in the EMERgency position or by simply displacing the emergency lever control from its centered position, regardless of the position of the Mode Selector Switch. When the Mode Selector Switch is in the EMERgency position, activation of the lever control will cause the rudder to move in the direction of the lever displacement until the lever is released. When the lever is released, the rudder will remain in its present position. The lever's centered position is a neutral or, in effect, a nonchange command position. Consequently, when the rudder is displaced from its centered position, the lever must be moved in the opposite direction to return the

rudder to amidships. For example, if the rudder is at 15°
left rudder, the lever must be displaced to the right to return
the rudder to amidships.

When the Mode Selector Switch is in either the Hand of
the Auto position, the operator can temporarily override either
of these modes and obtain direct control of the rudder simply
by displacing the lever control from its centered position.
(This will be true regardless of whether the Auto-Pilot Order
switch is in the BRIDGE or REMOTE position.) When the lever
control is released, the system will revert to the mode selected
on the Mode Selector Switch.

Rudder orders generated by the lever control will be displayed on the small rudder order indicator located just below
the ship's course indicator. Actual rudder position will continue to be displayed on the large rudder position indicator.

Actuation of the lever control will place the steering
gear electro-hydraulic system on full stroke and will cause the
rudder to move at its maximum rate of travel.

## Propulsion Control System

The propulsion controls will be located to the right of
the steering wheel on the Steering and Propulsion Control Console. There will be two speed control devices: a T-shaped
handle and a large, knurled knob. The T-shaped handle is intended to be used for gross speed control, i.e., ordering bell
and knot changes. The knurled knob will be used for making
fine speed adjustments, i.e., increments of single RPM's.

A selector control will also be provided to permit fine speed control (i.e., establishment and single knot adjustments of speed through the water) via the computer receiving inputs from the EM log.

The base of the T-shaped handle will be attached to a slide mechanism, which, in turn, will be attached to a synchro transmitter, which will transmit speed orders to Main Control and to the Fire Room.

The handle will slide forward to increase speed and aft to decrease speed. (When the ship is backing the opposite will, of course, be true. That is, while the ship is backing, forward movement of the handle will decrease backing speed and aft movement of the handle will increase backing speed.)

The knurled knob will be located adjacent to the T-shaped handle. It will be turned forward to increase speed and aft to decrease speed, in the manner of a large thumb wheel. The knurled knob will be coupled to the T-shaped handle. Movement of the knob will transmit speed orders from the Bridge to Main Control (and indirectly to the Fire Room, if the speed change entered using the knob results in a bell order change) via the T-shaped handle synchro transmission system. Moving an arbitrary reference point on the exposed area of the knurled knob from its full aft to full forward position shall be equivalent to a speed change order of 4 RPM's. Each RPM change will be accompanied by an audible click.

Speed Control Displays

There are two speed-control displays: linear and digital. The linear display will be located to the left and adjacent to the T-shaped speed control. The digital display will be located directly above the linear display (see Figure 31).

The Linear Display

The linear display will have three columns of information: an RPM column on the left, a standard bell order column in the center, and a knots column on the right.

The knots column will be graduated in increments of single knots, e.g., 0, 1, 2, 3, etc. The left-hand (RPM) column will be graduated in increments of the number of turns required to make a specified number of knots, e.g., 0, 8, 16, 24, etc. The middle column will be divided into nine sections representing the nine standard bell orders, i.e., Back Full, Back 2/3, Back 1/3, Stop, and the Ahead bells, 1/3, 2/3, Standard, Full and Flank.

The graduations and the distance between graduations for all three columns will be keyed to the knots display. For example, the line separating the 1/3 from the 2/3 bell order will lie precisely between 7 and 8 knots, i.e., at 7 1/2 knots. Also, the numbers in the RPM columns will lie opposite the appropriate knot increment; e.g., 0 in the RPM column will be in a line with the Stop or 0 position of the knots column.

Correspondence between RPM, bells, and knots will be maintained throughout the linear display.

A thin, transparent, black-outlined cursor will extend from the left-hand edge of the RPM column to the right-hand edge of the knots column. This cursor will be mechanically coupled to the T-shaped handle and will be controlled by the movement of the T-shaped handle.

### The Digital Display

The digital display will indicate ordered, and actual RPM or ships speed depending on selector switch position. A red astern light will also be provided to indicate when the ship's propeller shaft is turning astern.

Three digits will be presented for each of the RPM displays. (The digits are to be displayed on LED's, or equivalent display devices.) Only significant zeros will be shown on the display; i.e., 8 RPM's are shown as an 8 display, not as a 008 display.

## MISCELLANEOUS STEERING AND PROPULSION CONTROLS AND INDICATORS

### Fog Signal Timer

A three-position switch labeled INLAND, OFF, and INTERNATIONAL will be located on the Steering Propulsion Console. Actuation of the timer will cause the ship's whistle to sound

the fog signals prescribed by the Rules of the Road. (Fog signal timers are used extensively by the merchant marine and are commercially available.)

Ship's Whistle Control

A Spring-loaded push button which activates the ship's whistle when depressed will be on the console. Activation of the ship's whistle while the Fog Signal Timer is in operation shall temporarily disable the Fog Signal Timer. (The present mechanical ship's whistle handle shall be retained in approximately its present location.)

Speed Available Readout

The purpose of this readout is to inform and remind the operator of the maximum speed available. The input for this readout will come from Main Control and will be based on any blocking action being taken by the computer control system (Chapter VI). This is a new readout; no similar display exists at present.

Ship's Lights Control Panel

The Navigation Light Control Panel will be located immediately to the right of the Steering and Propulsion Control Console (see Figure 32). At the top of the panel will be

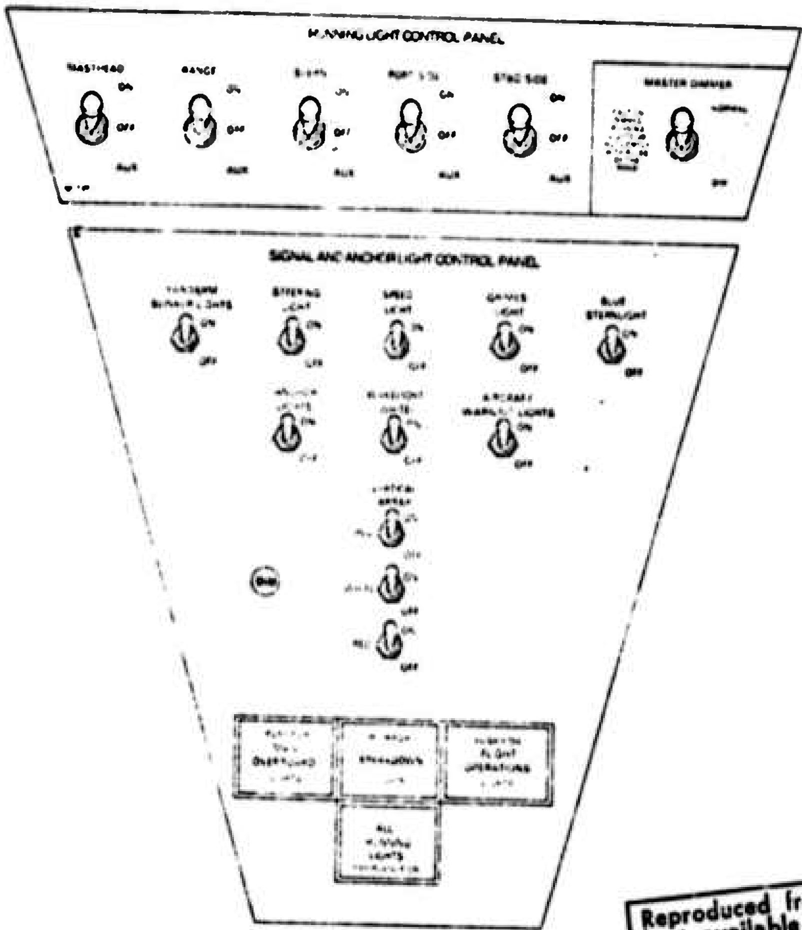




FIGURE 32

NAVIGATION LIGHT CONTROL PANEL

located switches for controlling the five running lights: Masthead, Range, Stern, Starboard Side, and Port Side. The Running Light master dimmer will be located adjacent to the Running Light switches. Beneath these switches the Signal and Anchor Light switches, yard arm blinker, steering, speed, Grimes, blue stern, anchor, wake, aircraft warning, and vertical array light switches.

Four special-function push buttons which override, if necessary, any switch settings currently in effect will also be located on the panel. A second depression of a special-function push button reestablishes the prior lighting configuration.

Pushing the "Man Overboard" switch will turn on the two red lights of the vertical array and cause them to pulsate. Pushing the BREAKDOWN button will activate the same two red lights, but without pulsation. The flight operations button, when pressed, will simultaneously turn the range and masthead lights off, cause the stern and sidelights to dim, the aircraft warning lights to turn on, and all other lights to turn off. A second depression of this switch will reestablish the lighting condition in effect prior to its first activation. The "All Running Lights Emergency On" switch will turn the normal running lights on bright when it is activated, regardless of any other switch positions on the panel.

All switches, with the exception of the yardarm blinker switch, will be detented toggle switches that remain in the position selected unless deliberately changed. These switches

are of the double-action variety. That is, to change the switch position, it is necessary to lift the toggle before changing the switch position.

The yardarm blinker switch will be spring-loaded. When placed in the "ON" position, it will cause the yardarm blinkers, located on the MACK, to transmit the standard procedure sign prosign) for "wait"--$\overline{\text{AS}}$, i.e., Morse Code for A and S without the normal pause between letters.

The Ship's Lights Control Panel is essentially a reconfiguration of the telltale panel on the present bridge.

## Fiddle Board Displays

The purpose of the fiddle board displays will be to present various types of status information (see Figure 33). The fiddle board will be approximately 1 foot high and 6 feet in length. It will be mounted at an angle that will facilitate its viewing while minimizing light reflections. The final mounting angle will be established by testing aboard ship during installation.

## Alarm Systems

Two types of alarms are provided--warnings and cautions. The purpose of both types is to alert bridge personnel to hazardous or potentially hazardous conditions existing at various locations about the ship.

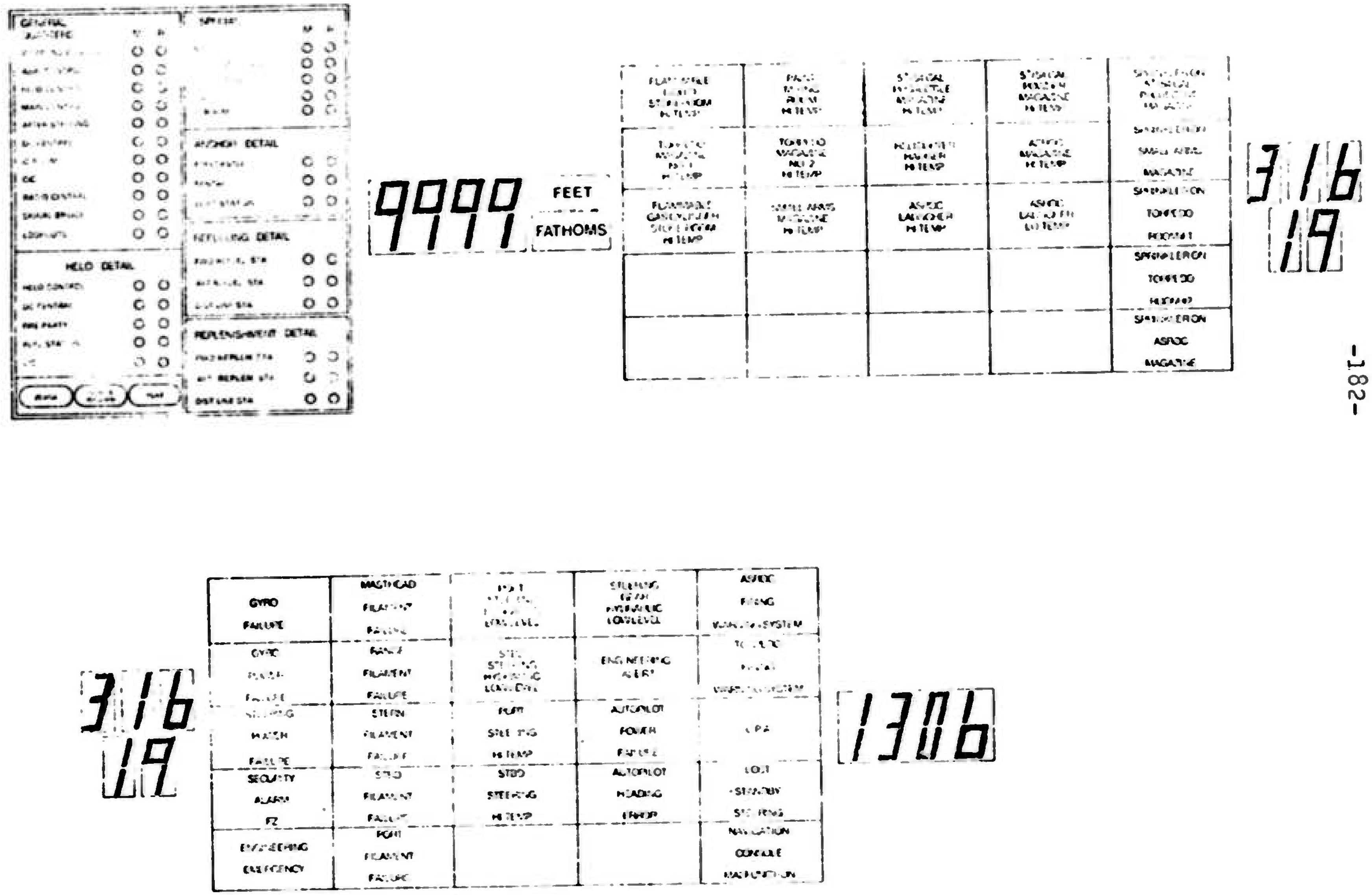


FIGURE 33

FIDDLE BOARD

Warning Alarm Display

Warning alarms will be sounded to alert bridge personnel of a situation requiring immediate action to avoid personnel injury or damage to the ship or its equipment. The red master warning light on the Steering and Propulsion Control console will begin to flash (4 on/off cycles/sec.), and an indicator on the fiddle board which will identify the specific problem causing the alarm will also flash at the same frequency. In addition, an auditory signal (80 dB, oscillating between 1500-2500 Hz twice a second) will be triggered. Depressing the master warning button will stop the auditory and flash signals, but the backlighted indicator on the fiddle board will remain illuminated until the problem is rectified. The warning alarms follows:

A. High Temperature

1. Flammable liquid storeroom.
2. Paint mixing room.
3. 5"/54 cal. projectile magazine.
4. 5"54 cal. powder magazine.
5. Torpedo magazine No. 1
6. Torpedo magazine No. 2

7. Helo hangar.

8. ASROC magazine.

9. Flammable gas cylinder storeroom.

10. Small arms magazine.

11. ASROC launcher high temperature.

12. ASROC launcher low temperature.

B. Running Lights (Filament Failure)

1. Masthead.

2. Range.

3. Stern.

4. Starboard.

5. Port.

C. Sprinkler Activation

1. 5"54 Cal. projectile magazine.

2. Small arms magazine.

3. Torpedo Room No. 1.

4. Torpedo Room No. 2.

5. ASROC magazine.

D. Miscellaneous

1. Gyro failure.

2. Gyro power failure.

3. Security alarm (FZ circuit).

4. Auto-pilot power failure*.

5. et. seq., at sea engineering emergency conditions, several*.

Caution Alarm Display

This system will be functionally identical to the warning system. It will, however, have its own amber-colored master caution button and display matrix. Its auditory signal will differ distinguishably from that of the warning system (80 dB, 500 Hz, on/off "beep" once a second.) Caution alarms will not necessarily be less important than warning alarms; however, they will not require as immediate a response as will warnings. The caution alarms are:

A. Firing Warnings

1. ASROC system

* The warning and cautions indicated by an asterisk are not currently available on the Bridge. The others are available in various locations about the Bridge.

2. Torpedo system.

B. Miscellaneous

1. Steering gear/hydraulic fluid low level*.

2. CPA alert*.

3. Collision avoidance range ring alert*.

4. Auto-pilot heading error*.

5. Steering gear hydraulic fluid high temperature.

6. Navigation console malfunction*.

7. et seq., at sea engineering alert conditions, several*.

For the most part, the purpose of both the old and new alarms is self-explanatory. The signals for the CPA and Collision Avoidance Range Ring Alerts will be obtained from the Collision Avoidance System. The signals for the auto-pilot power failure and auto-pilot heading error alarms will be obtained from the auto-pilot.

High Visibility Displays

Four items of information are in nearly continuous demand by all personnel on the Bridge--course, speed, time, and depth of water. These items will be displayed in large digits

* The warnings and cautions indicated by an asterisk are not currently available on the Bridge. The others are available in various locations about the Bridge.

on the fiddle board. These readouts will be visible from anywhere on the Bridge, including the chart house and bridge wings.

The course information displayed will be gyrocompass heading to the nearest degree; the speed will be electromagnetic log speed to the nearest knot; time shall be the time being used at the Navigation and Maneuvering console. The depth readout will be the depth of water under the sonar dome.

A digital depth readout is presently available on the DE 1052 bridge. Digital readouts of course, speed, and time are not presently available.

## Overhead Gyrocompass Repeater

The present centerline gyro repeater is to be removed. It will be replaced by an overhead gyrocompass repeater/sighting device of new design. The new device will be essentially an upside-down version of the present gyrocompass repeater. It will be mounted on a horizontal slide rod. This rod will be nine feet in length. The middle of the rod will be centered between the two operator stations. Sliding the gyro repeater along this rod will permit it to be used conveniently by either console operator. As the repeater assembly slides along this rod, the repeater card will maintain a fixed relationship with true North.

The athwartships movement will also permit offsetting the device to "see around" obstructions. The repeater assembly will latch positively in any selected lateral position.

Releasing the assembly will be accomplished by pressing either of two trigger switches, one mounted on either side of the repeater housing.

In addition to sliding laterally on the rod, the device will also move vertically, permitting it to be lifted up and out of the way of the operator (at either end of the fiddle board) when it is not in use.

The new gyrocompass repeater will have the same accuracy as any other gyro repeater; i.e., the observed error, if any, will be no greater than the ship's (MK-19) master gyrocompass.

OMEGA Navigation System

An OMEGA system will be provided with the IBS. OMEGA is an electronic navigation system that computes ship's present position continuously. Its display provides a direct readout of latitude and longitude and will be connected to the computerized navigation system.

The OMEGA display will be mounted from the overhead directly above the SPA-25 Radar Repeater (see Figure 22). It will be mounted facing to port so that its display surface will be visible to both IBS console operators and to a person standing behind the chart table.

TRANSIT Satellite Navigation System

A receiver for the TRANSIT satellite system of the U.S. Navy will be provided as an addition navigation aid and connected to the bridge navigation computer system.

Digital Clock

A digital clock will be provided which will serve as the time standard for the ship. It will be accurate within plus or minus 15 seconds per week. The clock will display hours, minutes, and seconds plus month, day, and year (each in two digits). The clock will have an auxiliary power source (battery) capable of sustaining its operation for at least 30 minutes following loss of its normal power.

This clock will serve as the time reference for the IBS console, the (bell) logger, and the voice tape recorder. In addition, it will be capable of driving up to six remote indicators (repeaters) which will be located in various spaces about the ship, e.g., CIC and Main Control.

Logger

This device will be an event recorder designed to automatically provide a time-referenced record of the ship's position and course and speed changes. The logger will consist of a printer assembly and the recorder unit itself. The logger will include the necessary sensing devices, conditioning circuits, converters, etc., that will enable it to obtain input signals from the ship's time reference clock, the OMEGA system, the gyrocompass and auto-pilot, and the propulsion controls and tachometer.

The logger will be an unmanned device. It will have only the following three, infrequently used, operator controls.

1. Rough Weather. This switch will reduce the recorder's sensitivity to course and speed fluctuations by one-half.

2. Manual Print. Each time it is actuated, this button will cause the logger to record (print out) a record of the nine data items listed below.

3. Manual Paper Advance. This button will cause the recording paper to advance one line.

Recording Criteria

Each time an event occurs that satisfies the criteria established for defining recordable events, a complete record of the following information will be printed out:

1. Data and time (from digital clock).

2. Ordered course (for auto-pilot mode only).

3. Gyro course.

4. Magnetic course.

5. Depth (from fathometer).

6. Latitude (from OMEGA, TRANSIT or computer dead reckoning system.)

7. Longitude (from OMEGA, TRANSIT or computer dead reckoning system.)

8. Bell order and RPM order (from propulsion control system).

9. Propeller shaft RPM (from tachometer).

The events that qualify as recordable events are course and speed changes. Different criteria will be used for defining a recordable event depending on whether the ship is being steered manually or by the auto-pilot. When the ship is being steered manually, recordable events will be defined solely in terms of heading changes. When the auto-pilot is in use, information related to ordered course as well as ship's heading will be recorded. The recorder will be designed to record both ordered course and speed changes, course keeping errors, and unordered fluctuations in ship's speed.

When the auto-pilot is in operation, a printout will be made: (1) when a ordered course change is entered, and (2) every 30 seconds thereafter for the duration of the turn. For recording purposes, the turn will be considered to have been complete when ship's heading agrees to within one degree of ordered course. Thereafter, a printout will be made for each two degrees of deviation between ordered course and ship's heading. For example, two printouts will be made if ship's heading deviates from ordered course by four degrees. When the rough weather function is activated, the auto-pilot course keeping deviation criterion will be four rather than two degrees.

When the ship is being steered manually, a printout will

be made for each five degrees of heading change (ten degrees in rough weather).

Two events related to ship's speed will trigger the logger's recording mechanism. A recording will be made when an ordered speed change is entered and every 30 seconds thereafter until ordered speed and propeller RPM agree to within five RPM. Thereafter, a recording will be made for each five RPM of deviation from ordered speed (ten RPM in rough weather).

In addition to the above event-dependent recordings, a printout will be made every hour on the hour and each time the manual printout button is actuated.

The logger will be designed so that it will continue to operate if any of its input signals are missing. However, if any of the inputs are missing, an alarm will be sounded to notify the watch standers of this fact.

## Voice Log Tape Recorder

A voice tape recorder will be provided to log the verbal communications of the bridge watch team and to allow the OOD to record significant events. This record, together with the logger printout and the collision avoidance system record, will provide a complete record of events both for legal purposes and for reconstruction.

The recorder's time reference will be the Bridge Digital Clock. The recorder will have a readout device which will display date and time, day, hours, minutes, and seconds when

the recorder is operated in the playback mode. The recorder will be designed to permit simultaneous record and playback. An audible and visual alarm will be provided to indicate a recording failure. The recorder will be capable of recording for at least 24 hours on a single tape.

Bridge Wing Communication System

This is a pilot house (Steering and Propulsion Control Console Operator) to bridge wing(s) communications system designed to facilitate communications between the Conning Officer and the ship control station during special sea detail evolutions. This system will have the following characteristics:

1. It will be a two-way system.

2. The console operator will have an open microphone (will not be required to press-to-talk).

3. The Conning Officer's orders will be broadcast in the pilothouse (to enable supervisory personnel to monitor the conning orders).

4. The Conning Officer will be permitted some freedon of movement while remaining in continuous communication with the console operator.

# CHAPTER IX

## SUPERVISORY CONTROL - THE LOG ROOM

### GENERAL

As described in Chapter II, the heart of the overall hierarchical computer control system, being proposed here for the automation of the operational (non-combat) function of the DE 1052 Class of Naval escort ships, is the dual minicomputer system to be installed in the Log Room or adjacent areas of the ship. In any case, all operating controls and displays would be located in the Log Room. The task of this particular pair of computers is to supervise and coordinate the operation of all other systems, to manage the communication system involved, to store images of the programs of all other systems, to serve as the ship's operational data storage location, and to serve as a backup system for any of the other computer systems which might fail in both of their dual elements. As mentioned, this central system will itself be redundant with one of the available computers serving as a standby backup element for the other.

The following items discuss some specific tasks assigned to this system beyond those described in earlier sections.

## INDICATION USING CATHODE RAY TUBE PRESENTATION OF ALL DESIRED POWER SYSTEM VARIABLES

The provision of this capability allows a much broader range of performance indication with less instrumentation than under the existing analog control system. Rather than providing individual instruments to record and display power system variables, the cathode ray tube (CRT) output device is used to perform this function for all desired information. This allows the engineering personnel to access all necessary information from one single location rather than having to reference several different instruments that may be located in remote spots in the Engineering Control Center or in the fire room.

Data collected during the normal operation of the engine plant is kept in compressed form, discarding all but the significant points for each variable. Any points that can be found by interpolation techniques are deleted. The retained data is then stored on disc memory for a specific length of time. As old data is removed from memory, new data is added to the memory file. The operator can then access this information, obtaining output from the computer-driven CRT unit in any desired format such as tabular or graphical form. The data can be presented for a number of time intervals from the past one or two hours up to the maximum time over which data is held in storage. This type of data presentation allows

accurate trend and condition monitoring for all power system variables instead of just those for which continuous recording equipment is installed.

There are many variables for which such data should be stored. A list of suggested variables which are critical and should be included in this monitoring and presentation system is presented in Table VI. Other variables are monitored and their present values can be displayed in tabular form on demand or at preselected intervals. This capability is provided for any information in the computer system. Further detailed study should be made to refine the list of Table VI.

The capability to print the values of any power system variables is also provided. This printing can be accomplished either at the direction of the engineering personnel or under the direction of the computer system. The logging of preselected critical data at predetermined and programmed intervals is a function of the data logging system which is performed by the supervisory mini-computer system located in the engineering log room. The logging of this data is performed as programmed and at order changes and during alarm conditions.

## SIMULATION CAPABILITY TO RUN OPERATIONAL CHECKS ON ANY PART OF THE COMPUTER SYSTEM

The supervisory mini-computer system contains a file of stored simulation programs that can be used to simulate out-of-limit conditions or casualty conditions for any of the

TABLE VI

CRITICAL VARIABLES TO BE MONITORED AND STORED IN COMPUTER MEMORY

1. Main steam header pressure.
2. Desuperheater outlet pressure.
3. Desuperheater outlet temperature.
4. Boiler steam drum pressure.
5. Superheater outlet pressure.
6. Superheater outlet temperature.
7. LP turbine exhaust temperature.
8. Main turbine gland steam pressure.
9. HP turbine first stage pressure.
10. HP turbine steam chest pressure.
11. 1200 psi auxiliary steam pressure.
12. HP turbine exhaust pressure.
13. 150 psi auxiliary steam pressure.
14. Lube oil to main engine - pressure.
15. Lube oil to main engine - temperature.
16. Lube oil cooler main propulsion outlet temperature.

TABLE VI (Cont.)

17. Lube oil service pump discharge pressure.

18. Lube oil cooler inlet temperature.

19. Lube oil cooler outlet temperature.

20. Lube oil pressure at the most remote bearing.

21. Lube oil pressure at the forced draft blower bearings.

22. Lube oil pressure at the feedwater auxiliary pump bearings.

23. Fuel oil service pump discharge pressure.

24. Fuel oil service common header pressure.

25. Fuel oil boiler header pressure.

26. Main condenser circulating water inlet temperature.

27. Main condenser circulating water outlet temperature.

28. Main circulating pump discharge pressure.

computer subsystems. The main computer selects and implements these programs at certain time intervals and at the direction of the engineering staff to check the response of all computer subsystems. These diagnostic routines will not interfere with the normal operation of the computer control system as a whole but will warn of malfunctions in the computer system and will cause the redundant back-up unit for the malfunctioning computer to take over the control and monitoring functions in its area of responsibility.

# CHAPTER X

## PROPOSALS FOR FUTURE WORK

### LAND-BASED SIMULATION OF SHIP OPERATION AND AT-SEA TRIALS

It is recommended that the proposed ship operational automation system described herein be developed. Depending upon the desires of the Agencies involved, these tests could take two forms:

1. Development of the overall computer control system, test and checkout of the individual elements in the manufacturers' or in Navy locations, installation of the total system aboard a DE 1052 Class ship and an operational test of the total system at sea under normal and simulated combat conditions.

2. This method of development and test includes all the items just about but involves a shore based simulation test of the total computer control system as a unit prior to its installation and test on shipboard. This second method will, of course, involve a considerably higher cost and greater time period than the former, but does have the advantage of developing any inherent system faults in a land-based environment.

Should the first suggested plan, the testing and

evaluation of the resulting proposed at-sea demonstration project be chosen, it will involve an estimated project timing as listed in Table VII.

## LAND-BASED SIMULATION

Should the Agencies involved choose the medium of a land-based simulation of the system prior to at-sea trials it is recommended that every effort be made to make these tests as realistic and representative of actual at-sea conditions as possible. In this regard, the following possible test system is proposed.

The Advanced Research Projects Agency operates the ARPANET which is a telephone network connecting some 45 separate computer systems located in universities and governmental research laboratories about the country. The U.S. Navy is building a land-based example of a Naval Destroyer Escort power system similar to that of the DE 1052 at its Great Lakes Naval Training Station. The Navy also operates a Damage and Casualty Control School at its Treasure Island facility in San Francisco Bay. The U.S. Maritime Commission is building a major ship's bridge system simulation facility on the grounds of the U.S. Merchant Marine Academy at King's Point, Long Island, New York, known as CAORF, or Computer Aided Operational Research Facility. It is therefore proposed that the appropriate elements of the overall computer control hierarchy system described herein be installed at each of the locations described above

TABLE VII

TIME SCHEDULE FOR DEMONSTRATION PROJECT

AUTOMATION OF NAVAL SURFACE SHIPS

May 16, 1973 - May 15, 1974 - PHASE I

Preparation of a plan of action for the maximum practical automation of the DE 1052 class of naval surface ships.

May 16, 1974 - June 30, 1975 - PHASE Ia

Solicitation of competitive RFI's for the development, production, installation and testing of a demonstration project on the maximum practical automation of the DE 1052 class of naval surface ships.

July 1, 1975 - June 30, 1976 - PHASE II

Analysis, basic engineering, and detailed design of the needed computer and related control equipment for the demonstration project by the successful bidder.

July 1, 1976 - June 30, 1977 - PHASE III

Construction and in-plant, acceptance testing of the prototype computerized control system as incorporated in the plan of action.

July 1, 1977 - June 30, 1978 - PHASE IV a

Installation; in-place, acceptance tests; and initial

TABLE VII (Cont.)

sea trials of the naval surface ship automation on a DE 1052 class naval ship.

July 1, 1978 - June 30, 1979 - PHASE IVb

Continuation and completion of the sea trials of the prototype system. Development of plans for a production system based on the results of the sea trials of the demonstration system. Preparation of final reports on the project.

and be programmed to carry out the same functions on the land-based elements as would be done at sea. The Log Room computer system would be installed at another location remote from any of those previously mentioned. All control system components would then be connected together as one system through the facilities of the ARPANET rather than the "serial data highway" actually proposed for the ship itself.

The result will be a representative Destroyer Escort system effectively spread across the country but operating as if it were an integral ship. Such a test should readily point out any deficiencies which might exist in the developed overall ship control system and should make their correction relatively easy prior to actual sea trials.

Carrying out these land-based tests in serial fashion with the at-sea trials will, of course, put approximately a three year delay in the time table of Table VI between Phases I and II of that Demonstration Project. Table VIII presents the corresponding timetable for the land-based test just described.

In order to permit the continuation of the land-based trials to an at-sea test, Table IX presents the corresponding time schedules for the combined tests. As mentioned earlier, an additional three year period will be reuqired for this dual test. The cost should be considerably less than the sum of the two tests because hopefully, if properly planned, only a small part of the engineering involved need be repeated for the at-sea test after the land-based test is successfully completed.

TABLE VIII

TIME SCHEDULE FOR LAND-BASED DEMONSTRATION
OF AUTOMATION OF NAVAL SURFACE SHIPS

May 16, 1973 - June 30, 1977 - PHASE I - PHASE III

Same as Table VII except for the land-based system instead of the ship-based system. All efforts would be made to minimize deviations between the land-based and at-sea designs of the control system involved, including computer programming.

July 1, 1977 - June 30, 1978 - PHASE IVa

Installation; in place, acceptance tests; and initial operation of the land-based simulation system through the facilities of the ARPA net.

July 1, 1978 - June 30, 1979 - PHASE IVb

Continuation and completion of the land-based trials of the prototype system. Development of plans for a continuation of tests through the at-sea trials. Preparation of final reports on the land-based projects.

TABLE IX

TIME SCHEDULE FOR COMBINED
DEMONSTRATION PROJECT LAND-BASED AND AT-SEA TRIALS
AUTOMATION OF NAVAL SURFACE SHIPS

PHASES I - IVb - Fiscal Years 1974 - 1979

Same as Table IX

PHASE V - Fiscal Year 1980

Same as PHASE III of Table VII except that as much as possible of the design material from the land-based demonstration will be used in the design, development and production of the at-sea demonstration equipment.

PHASE VIa - Fiscal Year 1981

Same as PHASE IVa, Table VII

PHASE VIb - Fiscal Year 1982

Same as PHASE IVb, Table VII

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